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# THE THEORY AND PRACTICE

OF

# HYDRO-MECHANICS.

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## A Series of Lectures

DELIVERED AT

## THE INSTITUTION OF CIVIL ENGINEERS,

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# PREFACE.

In the "Description of a Civil Engineer," written at the end of the year 1827 by Thomas Tredgold, Hon. M. Inst. C.E., (Minutes of Proceedings, vol. xxvii., p. 181), the science of hydraulics is stated to be one of the great bases on which the successful practice of engineering is founded. Hence, Water, in its varied aspects, as made subservient to "the use and convenience of man," came to be selected for the course of lectures on "The Theory and Practice of Hydro-Mechanics," constituting the present volume. The outline of Tredgold has been to a large extent followed by the Lecturers. Water has been dealt with in its general effects on the configuration of the surface of the earth, while the natural sources of supply, and the method of its collection and distribution for the use of towns, have been described. Water, as distinct from steam, has also been regarded as an agent for operating various classes of machines, and next as presenting, in trained rivers and in canals, a highway for internal or Inland Navigation. Subsequently the waves of the ocean have been considered in their influence on the design and construction of Harbours, Ports, and Docks, as well as on the Forms of Ships.

With this series the Lectures will for the time cease, as it was never intended that they should form a permanent addition to the business of the Institution, but should only be given occasionally, and under exceptional circumstances.

It is a source of much gratification to the Council that the above Lectures, as well as those on "The Practical Applications of Electricity," and on "Heat in its Mechanical Applications," were all delivered by Members of the Institution.

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## THEORY AND PRACTICE

OF

# HYDRO-MECHANICS.

15 January, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

## "Physiography."

By JOHN EVANS, V.P. and Treas. R.S., Assoc. Inst. C.E.

THE Council of the Institution of Civil Engineers having determined on the delivery of a course of lectures on the Theory and Practice of Hydro-mechanics have done me the honour of requesting me to give the first of these lectures, and have suggested "Physiography" as my subject. At the time that I expressed my willingness to comply with this request, I hoped that I should be able to find sufficient spare hours to do some justice to the subject, but, unfortunately, owing to the absence of the President of the Royal Society, unexpected duties have devolved upon me, and the small modicum of leisure which my ordinary avocations allow me has been considerably cut down. I must, therefore, beg for some indulgence if in the following remarks I seem to treat my subject in an inadequate manner, and do not in some respects enter into the amount of detail which might not unreasonably have been expected.

But what is my subject? The word "Physiography"—for which as a title to my lecture I must deny all personal responsibility—is one of very wide import, and has been defined in the dictionaries as meaning "a description of nature, or the science of natural objects." I shall not attempt to accept the word in this wide sense, or the limits of one, or even of a dozen lectures, would not suffice for the treatment of the subject. And moreover it has already been admirably worked out by Professor Huxley in his course of lectures at the London Institution, which have been expanded into a most instructive volume with the title "Physiography," a work that I have found of some service in preparing for this evening. What I hope to do, is to bring before you



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such portions only of this great subject as bear more especially on the supply of that indispensable necessary of life with which in various ways the lecturers who follow after me will have to deal, and I must moreover limit myself, so far as possible, to the phases of nature which may be observed in our own country.

The water which we consume for our daily use is usually derived from one of three sources—springs,—streams, rivers or lakes,—or reservoirs of some kind in which the rainfall is artificially stored. In all cases, however, the water comes to us more or less immediately from the clouds, and they in turn are fed by evaporation from different parts of the surface of the globe. The principal source whence the air derives its moisture is no doubt the ocean from and toward which there is a constant circulation of water. As was said by the wise man of old,[1] "All the rivers run into the sea, yet the sea is not full; unto the place from whence the rivers come, thither they return again."

The air, then, is the great conductor of moisture from the sea and other sources to the springs and streamlets which feed the rivers, and the term "atmosphere"—the sphere of vapour—fittingly describes under one of its most beneficent functions the attenuated fluid which envelops our globe. I need hardly enter into the chemical nature of water, which consists of oxygen and hydrogen in the proportion of one to two, nor into that of air, which is in fact a mixture of about one part of oxygen-gas, with about four of nitrogen. To speak accurately, if we take 100 cubic feet of pure air, they will consist of 20·9 feet of oxygen and 79·1 feet of nitrogen. If, on the other hand, we take 100 lbs. of pure air, it will be found that they consist of about 23 lbs. of oxygen and 77 lbs. of nitrogen. Air, however, as a rule, is not absolutely pure, but usually contains about four parts in the one thousand of carbonic-acid gas, as well as smaller proportions of ammonia, hydrogen and nitric acid. These may all have some slight effect on water falling through the air, but in considering the air as an absorbent of aqueous vapour, these minor constituents may be entirely disregarded. Practically the air is never free from this aqueous vapour, for however dry it may appear, yet when tested by powerful absorbents of moisture water is constantly found present. The hotter the air the more capable it is of absorbing moisture and holding it in invisible suspension, we might almost say in solution. On the coldest day, however, the air retains some power of absorbing moisture, and

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[1] Ecclesiastes i. 7.

will even carry it off from snow or from a lump of ice. As water itself under ordinary circumstances is converted into steam at a temperature of about 212° Fahrenheit, it is evident that with air at this or a higher temperature an invisible admixture of air and water might exist in almost any proportions. For it must be borne in mind that the ordinary conception of steam being visible is entirely erroneous. It is not until it has to some extent been condensed and reduced into small particles of water that steam assumes a visible consistence. If on a bright day we watch the steam blowing off from the safety-valve of a locomotive engine we can observe three phases. Close to the valve there is little or no appearance of vapour, next we can observe volumes, in fact clouds, of visible steam being gradually formed, and as these are wafted away in feathery streaks by the wind they gradually disappear, the vapour having been absorbed and incorporated in the air, to be again deposited in the form of a visible cloud and eventually of rain at some future and possibly long distant time.

The quantity of moisture present in the air varies considerably in different countries and at different seasons. Here in England it is said that the average proportion of water present in the air is about 1½ per cent. When the air at an ordinary temperature is nearly saturated, a slight reduction of heat suffices to make the moisture visible. How often do we not observe a mist rising, as it is called, towards sunset, after a bright warm day; and how often have we not seen the morning's mist, and even the clouds at a higher level, gradually disappear under the genial influence of the sun's rays.

The power of the air to carry off vapour has been put to the test by various experimental researches. In our own country Howard at Plaistow, Greaves at Lea Bridge, Lawes and Gilbert at Rothamsted, and others have investigated the subject. From shallow vessels at Plaistow, and from a larger surface of water at Lea Bridge, the annual evaporation was about 21 inches per annum, and, as might be expected, the quantity varied at different seasons of the year. Speaking roughly, it was about as follows:—January to March, 4 inches; April to May, 8 inches; June to September, 7 inches; October to December, 2 inches. At Dijon about 26 inches were carried off from the surface of large vessels of water. Extensive observations made in Denmark show about 28 inches from water, 30 inches from short grass, and 44 inches from long grass.

In hotter regions the evaporation must be greater still; and I may just refer to the Dead Sea, into which the river Jordan is constantly flowing, and which, notwithstanding, is kept by evapora-

tion at a level of more than 1,300 feet below that of the Mediterranean. Even the Mediterranean itself affords another instance of the wonderful power of the sun; for notwithstanding the volume of water poured into it and the inland seas connected with it by the larger rivers, such as the Rhone, the Po, the Danube, the Dnieper, the Don, and the Nile, this accession to its waters appears to be insufficient to keep pace with the evaporation from its surface, as notwithstanding occasional outward undercurrents, there is almost constant inset of the current through the Straits of Gibraltar. At Madras it has been found that there is an annual evaporation of about 90 inches; and from a reservoir at Nagpoor, evaporation went on at the rate of one-fifth of an inch per diem, so that 48 inches disappeared in the course of two hundred and forty days. At Dublin, on the average of two years, Dr. Haughton found that the evaporation fell short of the rainfall by only 1 inch. In fact Mr. R. H. Scott thinks that in nearly all parts of the globe, the evaporation from a free water surface is on the average about equal to the rainfall. The effect of wind is largely to increase the evaporation, and the hot winds of the equatorial regions, acting on the surface of a warm sea, become highly charged with vapour. It is indeed mainly from the surface of the ocean that the supply of aqueous vapour in the atmosphere must be derived. The fine warm weather which dries up a land surface until but little moisture is left to evaporate, makes the air which is brought in contact with the waves of the sea all the more avid to receive water, of which it then finds no stint. How readily the air parts with some of the moisture suspended in it, when brought in contact with a cold surface, is well shown by the hackneyed example of a glass of cold water brought into a warm room. The effect of currents of colder air meeting warmer currents fairly charged with moisture is first evinced by the condensation of minute particles of water, which, though still in suspension in the atmosphere are visible in the form of cloud, mist or fog. A greater or more continued chill causes these particles to increase in size, coalesce, and descend as rain, hail, or snow.

In falling from the clouds rain increases in quantity as it descends, probably by the absorption of vapour, or of minute particles of water in the state of mist. Experiments have shown that this increase is very marked. Even at 3 feet from the ground there is said to be two per cent. less of rain than at the surface; at 20 feet twelve per cent.; and at 50 feet twenty-three per cent. It is, nevertheless, somewhat doubtful whether this law of increase universally holds good. While, however, in an open plain there

is less rain at a considerable height above the ground than at the surface, somewhat different conditions prevail in mountainous districts, for the actual amount of rainfall increases as a rule as we ascend the slope of a mountain. Mountain ranges indeed are the great condensers of atmospheric moisture, and the amount of rainfall of any country is in the main dependent on the position of these ranges, and the prevailing direction of the winds.

India affords a good example of this fact, as the trade-winds, or "monsoons," as they are there called, exhibit great regularity in their occurrence. From the end of October until the end of April there is little or no rain on the western coast, but during the other six months, after the monsoons have set in, rain falls in abundance. At Bombay, near the sea-level, the most rainy months are those of June and July, during which from 40 to 50 inches annually fall. During the whole of the rainy season the average of seven stations at the sea-level in the Bombay Presidency is about 80 inches. At an elevation of about 900 feet in the Southern Concan Hills or Western Ghâts there is an increase to about 135 inches, and at Mahabuleshwur, at a height of 4500 feet, and at a distance of 130 miles from the sea, the annual fall is over 250 inches. It is rarely that the hot stratum of aqueous vapour brought from the equator by the south-west monsoon floats at a higher level than this. In dashing against the precipitous western face of the Ghâts much of the warm stratum is thrown up among the colder layers of air at higher levels; but a little is carried eastward to be condensed by the Himalayas. So effectually does this high range do its work that the great plain of Tibet to the east may be regarded as rainless. In the same manner while the great central plains of Spain, at an elevation of 1200 feet or more above the sea, are during the summer months pinched with drought, the seaward face of the mountains that skirt the Bay of Biscay are clothed with verdure and rarely in want of rain.

Great as are the variations in the rainfall in India, they may be equalled, if not exceeded, by those in the British Isles. With us the Gulf Stream with its warm current seems to play an important part in supplying vapour to the atmosphere, and in charging our southern winds with moisture. A glance at a Hyetographical or Rainfall map, such as that prepared by Mr. G. J. Symons, of which he has kindly lent a copy, will at once show how disproportionate is the amount of rain which falls on the western and southern shores of England as compared with that on the eastern. Along our western shores the usual fall is from 40 to 50 inches, and in many districts from 50 to 75 inches; that of the southern coast is from 30 to 40 inches;

while in the eastern counties it is less than 25 inches. In some exceptional positions, such as Seathwaite in Cumberland, the average rainfall is upwards of 140 inches. In others, such as Hunstanton in Norfolk and some parts of Lincolnshire, it is little more than 20 inches; so that in effect there is on an average seven times as much rain in one part of England as there is in another. I am here speaking of an average of about twenty years, but in most places the annual variation is very great, the maximum annual fall being very much in excess of the minimum. Taking for instance the rainfall of 1852 and comparing it with that of 1854, I find that in Hertfordshire we had in the former year rather more than 41 inches, and in the latter a little under 19 inches, or less than one-half; the average of forty years being about 27 inches. Of course in estimating the water-supply of any district, it is the minimum rainfall on which the engineer must base his calculations, and not the average.

Mr. G. J. Symons has carefully considered the limits of fluctuation in the total rainfall, and has arrived at the following conclusions, basing them upon the observations of a long series of years.[1] In any part of this country—

1. The wettest year will have a rainfall of nearly half as much again as the mean.

2. The driest year will have one-third less than the mean.

3. The driest two consecutive years will each have one-quarter less than the mean.

4. The driest three consecutive years will each have one-fifth less than the mean.

At places, however, where the average rainfall is large, the extremes both of wetness and of dryness will be less pronounced than at those where the usual rainfall is small.

I have already mentioned the gradual increase of the rainfall in India as the slope of a mountain is ascended. It has, however, been assumed that, though in this country there is a gradual increase up to about 1,500 feet, yet that above such an elevation it decreases. It has indeed been calculated that one-half of the vapour in the atmosphere is contained in the lowest 6,000 feet, and that at a height of 20,000 feet, there is only one-tenth of the moisture that there is near the surface of the earth, so that at extreme elevations there must be a diminution in the rainfall. Dr. Hann has well pointed out, "There must on high mountains be an upper limit of the maximum amount of rain. The decrease

[1] "British Rainfall," 1883, p. 32.

of temperature with increasing elevation involves a decrease in the amount of vapour held in the air. The maximum rainfall is, therefore, to be expected at the height at which, as a rule, condensation is first produced." As the usual height of *nimbi*, or rain-clouds, is in these latitudes not more than 1,500 feet, and as some of the observations in the Lake District seem to show a decrease above that level, the assumption just mentioned has been commonly accepted as true. Recent observations, however, in the Mountain Observatory on the summit of Ben Nevis, at an elevation of 4,406 feet, compared with those taken near the sea-level at Fort William at the foot of the mountain and at the lake, which is at a height of 1,840 feet above the sea, show that while at the lake the increase of the rainfall is about 30 per cent., it is at the summit fully 100 per cent.; in other words, twice as much rain falls on the top of Ben Nevis as at Fort William at the base of the mountain. It is, however, right to say that the observations on which this calculation is based extend over two seasons only, viz., the five months from June to October inclusive, in the years 1882 and 1883. During the other seven months of the year, so much snow falls at the top of the mountain, that exact measurement is impossible.

Our rivers and springs in this country are, as a rule, so little dependent upon the melting during the summer, of the snow that falls during the winter, that I need hardly do more than allude to the glaciers, which, in the case of many continental rivers, are during the summer months their main source of supply. With us, however, the rapid melting of snow is a frequent and principal cause of floods, especially in the case of districts consisting of porous soil, the surface of which has been hard-frozen before the snow fell upon it. Under ordinary circumstances the gradual melting of snow makes it play much the same part as an equivalent amount of rain. At a rough estimate 12 inches or 1 foot of undrifted snow may be taken as equal to 1 inch of rain.

Let us now consider what becomes of the rain, hail or snow after it falls upon the surface of the earth. With regard to the two latter forms in which water descends from the clouds we may leave them as they lie, inasmuch as until they assume a liquid form they remain upon the surface of the ground and do not add to the water-supply, being, however, still liable to diminution from evaporation. As to rain, however, or the liquefied snow or hail, the future course which under different conditions it may have to follow cannot at once be predicated. Although the utmost it can achieve is to remain undiminished in quantity, the falling rain in

many respects resembles the good seed in the parable, though that which falls in stony places is perhaps that which produces the most abundant results. The amount and quality of the water-supply from a given amount of rain are, in fact, most immediately connected with the geological character of the country in which it happens to fall, or through which it passes before being utilized.

If for instance we assume a tract of country to exist, consisting of bare, impervious, and unfissured rock, but the surface traversed by valleys all converging to one common outlet, it must be evident that the whole of the rain which falls upon it, less some small quantity carried off by evaporation, will in a short space of time be delivered by that outlet. If instead of a complete valley system there happen to be some depressed portions forming basins, apart from the valley system, the rain will accumulate in these, and there remain until carried off by evaporation; or if the rainfall is in excess of the evaporation, the basins will gradually fill, until they arrive at a level at which they can overflow into some part of the valley system. In wet years this overflow may be nearly constant, in average years intermittent, and in dry years it may cease. Assuming again that these basins occupy the half of the area under consideration, it will be seen that while during some portions of a wet year nearly the whole of the rainfall would find its way into the outlet, during a dry year only one half of it would do so, the remainder being retained by the lake basins, and there evaporated.

If instead of the rock being absolutely bare, there were a certain amount of superficial soil and vegetation upon it, the case would again be altered. Any moderate showers falling upon the area would be absorbed by the soil and the plants upon it, and but little would find its way to the outlet. A few days of fine weather would, in the summer months, when vegetation was in progress, suffice to render the superficial soil again dry and absorbent, so that practically during those months the water passing by the outlet might bear but a small proportion to the rain that fell. In the winter months, on the contrary, the proportion would be inordinately increased, and even were the rock bare it would be greater than in the summer, as the loss from surface evaporation would be less. In the case of the rocks being fissured, assuming them to be of an absolutely impervious kind, the result of the existence of fissures, provided they led down to no absorbent stratum, would not materially differ from the results of the presence of lake basins within the area, though the loss from evaporation would be less.

These are of course merely assumed cases, intended to show how variable may be the results of the same amount of rainfall under different conditions, although in some of our mountainous districts nearly analogous instances may be found. And it is principally in elevated tracts of country that hard and almost impervious rocks, like granites and gneiss, occur. In such tracts, the rainfall is usually great, and as the amount lost by evaporation is nearly a constant quantity, the proportion of the rainfall which finds its way into the streams and rivers is large. In the Loch Katrine district, with a rainfall at the head of the loch of 103 inches in 1854, it has been calculated that 82 inches were discharged from the loch, showing a loss from evaporation and other causes of 21 inches.

The outflow from a district formed of heavy clay land will differ from that which results from rain falling on impervious rock, inasmuch as in dry seasons the clay becomes fissured by contraction to a considerable depth, and though practically impervious, it is by no means unabsorbent. As a rule too in this country such heavy lands are now artificially drained; and tracts of which in old times the surface became charged and soddened with water, that either discharged itself gradually by natural channels, or was evaporated by the sun and wind, have now had their character modified to such an extent, that the rain which falls upon them is absorbed and delivered by the drains into the streams and rivers within a comparatively short time after it has fallen.

In old geological times floods seem to have played a much more important part than they do at the present day, but they still cause great difficulties and dangers with which the engineer has to contend. I need not, however, dwell upon these.

Both in clay districts and those formed of impermeable rocks it frequently happens that there are superficial patches of drift gravels or sands. These being of an absorbent nature, are after heavy rains highly charged with water, some of which is subsequently delivered from them by gravity at the lowest outfalls, forming what in some districts are called land-springs. On permeable rocks, on the contrary, there are occasionally patches of impermeable clay, such as the Tertiary outliers which occur on the chalk; and these being again capped by permeable beds form small water-bearing basins. The position of villages on chalk hills is often due to the circumstance that a supply of surface water is thus made available. Indeed as a rule there are hydrogeological reasons for most sites of human occupation.

Although not entering into minute details, Mr. De Rance has

given a hydro-geological map of England, which for the general features of the country is extremely instructive. In it he has divided the character of the soil into four divisions: the impermeable; the partially porous; the "supra-pervious," or clays resting on permeable rocks; and the permeable. In comparing this with the Hyetographical map, it is at once seen how closely the areas of greatest rainfall correspond with those of the impermeable rocks. Nor is this to be wondered at, as these harder rocks have been better able to withstand the wear and tear of rain and rivers and the other denuding forces, and are therefore at a higher level and brought into closer contact with the water-yielding clouds than the districts of softer rocks at a lower level. Roughly speaking, the western part of England and Wales consists of impermeable and partially porous rocks, and the eastern of the "supra-pervious" and the permeable, the area of the latter preponderating. Many of our river basins consist of rocks of two or more of these different kinds, and in consequence the flow and the character of the water in the rivers varies much from time to time. In wet weather many are subject to floods, owing to the water from impermeable and "supra-pervious" rocks being delivered into them. At such times their waters will be turbid, and probably contain less matter in solution than during dry weather, when they are mainly fed by springs rising out of the more pervious rocks, such as sandstone, limestone, and chalk.

The areas of the catchment basins of our rivers, and the extent and character of their flow, have of late years all been fairly well determined, and I need not enter into details concerning them. The streams and rivers form as it were parts of an extensive superficial drainage system, and the valleys through which they pass, though some are of old geological date, have in the main been excavated by the streams themselves aided by the action of rain and frost.

To return to the history of the fallen rain. In addition to the supra-pervious beds, of which I must say a few words further on, a very large portion of England—and it is this part of the United Kingdom with which I believe we are here more particularly concerned—consists of more or less absorbent rock underlying a still more absorbent superficial soil, and it is to this fact that the comparatively permanent character of most of our rivers is due. It will be well therefore to consider in some detail the history of the rain falling upon such soils, from the time of its fall until it is well on its course to the sea. And for the present it will be best to leave aside any questions as to the proportion

of it lost by evaporation and vegetation. Any moderate rain falling on an absorbent soil, whether ploughed or covered with grass, at once disappears from the surface, and finds its way among the particles of the soil. In light soils, so universally is this the case, that even in heavy thunderstorms it is of rare occurrence that the water accumulates on the surface in such quantities as to run down the slope of a hill. As a consequence, in districts consisting of such soils, floods are almost unknown, and when they do occur are usually due to one of two causes. First, that the ordinary channels of the stream are insufficient to carry off the water delivered into them from the lanes, roads, and roofs of the district in which a heavy storm has fallen, for of course all these are unabsorbent; or, secondly, that the surface of the soil is hard-frozen, and thus, as it were, waterproofed at the time of a heavy fall of rain, or a rapid thaw of snow.

The capacity of some soils or rocks for holding water in the interstices of their substance is great. In the case of the New Red Sandstone of Liverpool, Mr. Isaac Roberts found that it would absorb $\frac{1}{22}$ of its own weight of water, of which about one half would not drain away, as it was held in the pores of the stone by capillary attraction. In loose sand and chalk, it has been stated that the absorption is from $\frac{1}{12}$ to $\frac{1}{8}$ of the weight, or at the rate of 2 gallons to the cubic foot. In oolites and limestones the proportion is less, but a cubic foot will still absorb from 10 to 14 pints of water. With continued rainfall, anything in excess of what can be retained by capillary attraction gradually gravitates downwards until it arrives at a point where the rock is already charged with water. In the bottom of valleys with streams running along them, this saturated rock or soil will be met with near the surface, but the rain falling on hills may descend hundreds of feet before arriving at the point where its further progress is stopped by the spaces in the soil being already occupied with water, and then its effect is to add to the height of the already saturated portion. It will be asked, what is it that keeps the bottom of the valleys charged with water, and prevents the water under the hills from finding some method of escape? and the answer is, friction. Could friction be removed, the surface of the saturated rock would present a nearly dead level, and the rain would escape at the lowest vent almost as quickly as it penetrated the ground. It is true that in most districts the absorbent rocks, such as sandstone, limestone, and chalk, are underlain geologically by non-absorbent beds, such as clay, which prevent the rainfall from percolating to so low a level as that of the sea: but the inclination of the surface of the fully-

verse valleys, running into some main valley in which there is a stream. Assuming that the inclination of such a transverse valley is 20 feet to the mile, it is evident that so long as the inclination of the plane of saturation is at a less gradient, no water will be visible above ground; but so soon as the 20 feet is exceeded in consequence of a wet season, the bottom of the valley intersects the plane of saturation, and it becomes the course of a stream which continues to run until the angle of the plane of saturation again becomes less than that of 20 feet to the mile. When the bottom of the valley is uneven, and the slope of the plane of saturation nearly corresponds with the mean of that of the valley, the phenomenon is seen of a watercourse running at intervals along the bottom of the valley, the water finding its way underground where there are prominences in the land-surface.

Although the whole of the chalk below the plane of saturation is full of water, and more or less pervious in every direction, yet as the surface of the plane descends, the water, in escaping into the valleys, follows certain lines of least resistance, and thus in many places gives rise to springs sometimes of great volume.

In the upper portion of the chalk there are usually layers of nodules of flint, extending over large areas and occurring at intervals of 3 or 4 feet, the one over the other. Among these flints the underground water seems often to find its way more readily than through the interstices and crevices in the chalk itself; so that, in boring, an accession of water is obtained directly a layer of flint is traversed. So readily do these waterways communicate with the stores of water at a higher level, that the water in a deep boring in the bottom of a valley will rise higher than the level of the stream running through it, and overflow into its course.

From deep borings the water generally rises at a higher temperature than from ordinary springs. The water from the well-known artesian well at Grenelle, close to Paris, has a temperature of 82° Fahrenheit, and comes from a depth of rather more than 1800 feet. This temperature is about 30° above that of the springs of the district, showing an increase of about 1° for every 60 feet of descent. At the bottom of the deep boring lately made at Richmond, 1334 feet from the surface, the water has been found to have a temperature of 75½° Fahrenheit, from which an increase in heat of 1° to every 53 feet in depth has been deduced. This increase in temperature in descending from the surface seems universal, though varying in degree in different localities; and it seems probable that in most cases the heat of thermal springs is due to the fact that the channels through which the

water has to pass between the time when it is received into the ground at one place, and that at which it reappears at another, descend to a great depth from the surface.

But to return to the chalk. Where this rock is overlain by stiff clay, through which, however, it in places penetrates, what are known as swallow-holes are formed; and the rain, falling on tracts of impervious clay, forms streams, which find their way to such swallow-holes and disappear in the chalk. In such cases it seems probable that by the continual delivery of large bodies of water into one place the lines of least resistance in the chalk have been widened out by combined mechanical and chemical action, so that subterranean watercourses are formed. The caverns, which occur in so many limestone districts, often owe their origin to nearly similar causes.

It not unfrequently happens that pervious strata lie between others of an impervious character, forming, as it were, a porous basin placed between two other basins. In such cases the pervious beds become saturated with water, and the excess of the rainfall finds its way towards the sea over the exposed portion of the beds. A boring made through the upper impervious basin will tap these water-bearing beds, and if the exposed portion is at a higher level the water will probably rise to the surface, or even higher, and form a true artesian well. Of course, any water taken from this well will eventually affect the plane of saturation at the exposed portion of the beds, and, assuming that there is no disturbing element, the flow of the streams over them will be diminished to the extent of the water taken from the well. In some cases the naturally pervious beds beneath the impervious are so much consolidated by their weight, that the free passage of water through them is impeded, and though at first the artesian wells yield an abundant supply, it gradually diminishes, and pumping has to be resorted to, so that eventually a cone of depression is formed around the wells. I need hardly do more than mention the deep wells in the chalk under London as an instance of this phenomenon.

I have hitherto been speaking of the rainfall as if the whole of it that sank below the surface found its way to the saturated portion of the pervious rocks. This, however, is far, very far indeed, from being the case. During the summer months the amount of the rainfall carried off by evaporation, and by the vegetation which is going on all over the surface of the ground, is very large, often fully as great as the rainfall; and even during the winter, unless the rainfall has been continuous, it penetrates but a little way into the ground, and does not get beyond the reach of the evapo-

rating power of the sun and the air. We have only to turn over a few spadefuls of earth to see how small a distance even a heavy shower penetrates a dry soil.

The first to make experiments on the subject of the proportion of percolation through about 3 feet of soil to the rainfall on the surface were Dr. John Dalton, of Manchester, and Mr. Maurice, of Geneva, about the end of the last century. Since that time numerous experiments have been conducted by various observers both here and abroad. The principle on which they have been carried on is much the same in all cases. An impervious vessel, open at the top, is sunk in the ground so that the sides, which are brought to a knife-edge, barely protrude above the surface. It is then filled with soil of the character on which it is proposed to experiment, and the surface is either left bare or clothed with vegetation. From the bottom of the vessel a pipe conveys any water that penetrates so far from the surface into a suitable receiver. This is carefully measured and its volume compared with that of the rain falling on the surface as ascertained by an ordinary gauge. It has generally been supposed that water which has descended 3 feet from the surface of the ground is beyond the influences of evaporation and vegetation. Capillary attraction seems, however, capable of bringing up water from a greater depth; and the roots of some plants will find their way farther than 3 feet, as will also worms. The difference, however, between the quantity of water which out of a given rainfall descends 3 feet and that which descends 5 feet is not large. The results of many experiments on percolation have been recorded in the Proceedings of this Institution, and those of Mr. Charles Greaves and of Sir J. B. Lawes and Dr. Gilbert are especially worthy of notice. In the latter case the gauges, instead of being artificially filled with soil, were constructed round blocks of the natural soil with a surface area of $\frac{1}{1000}$ part of an acre, and a depth of 20, 40, and 60 inches respectively. The surface of these plots was kept free from vegetation by being occasionally hoed, and the following were the results for the ten years 1871 to 1880. Out of a mean rainfall of 31·451 inches, 14·040 passed through 20 inches of soil, and 13·241 through 60 inches; or, dividing the years into summer and winter periods of April to September, and October to March, it appears that out of 16·365 inches of summer rain only 4·111 found its way through 60 inches of soil, while in the winter there passed 9·130 inches out of a rainfall of 15·086 inches.

I think that I may claim for my uncle, the late Mr. John Dickinson, the honour of being the first in this country to

repeat the experiments of Dr. Dalton. His observations began in 1836; but new gauges, formed of cast-iron, were fixed at Nash Mills in 1853, and have been in continuous operation ever since under my own directions. One of the receivers is filled with the surface soil of the district, as nearly as possible as it occurs in nature, and the other with broken chalk, the surface in each case being covered by growing grass. I do not say that the experiments are so fully carried out as those of Mr. Greaves and Dr. Gilbert and Sir J. B. Lawes, inasmuch as the receivers are smaller, and the soil artificially introduced; but they have the merit of being continuous, and in their general results they are corroborated by the observations of others. I have therefore arranged the results of thirty years' observations in a diagrammatic form on the accompanying Plate. The plain vertical lines show the rainfall in each year from October 1 in one year to September 30 in that following; the winter rainfall being shown below the central horizontal line, and the summer rainfall above it. The percolation through 3 feet of soil is shown in a similar manner by broken vertical lines, and that through 3 feet of chalk by broken and dotted lines. The three diagrams are not superimposed the one on the other, but for the sake of clearness those showing the percolation are placed to the right of that showing the rainfall.

The average of the thirty years shows that out of a total rainfall of 27·843 inches, 6·519 passed through 3 feet of soil and 10·650 through the same depth of chalk.

Out of the winter rainfall of 13·752 inches the percolation was 5·707 inches and 8·532 inches; but out of the summer rainfall, when vegetation was in progress and evaporation greater, the amounts are 0·812 and 2·118 respectively out of a rainfall of 14·091 inches. The variations in the proportion of the percolation to the rainfall are very great, even in the winter half-year, so much depending upon the manner in which the rain falls, and whether it is constant for some days or intermittent. I will not detain you with figures, but will give one or two instances of maxima and minima. In the winter of 1879–80 only 5·84 inches of rain fell, of which 2·79 entered the soil to a depth of 3 feet, while in the winter of 1870–1, with a fall of 12·54 inches, only 0·208 percolated.

In the winter of 1882–3, no less than 22·67 inches fell, with a percolation through 3 feet of soil of 11·67 inches, and in that of 1880–81, 13·59 inches percolated out of 20·07 inches. In the summer of 1870 only 7·59 inches fell, and none percolated;

whereas in the summer of 1879, 25·09 inches of rain fell, and 6·94 inches percolated.

With a fall of 11·69 inches in the winter of 1874–5, 4·15 inches percolated; whereas 9·64 inches in 1858–59 gave only 0·09 inch. In the summer of 1859, 18·09 inches gave no percolation, and in that of 1870, 18·46 inches gave 2·16 inches.

It cannot be too often insisted on that, in the case of water-supply derived from porous soils, it is in the highest degree illusive to depend upon averages. The minimum, or at the best, the lowest average of three successive years, is the utmost on which we can rely. Taking the triennial period 1862–4, we find that, with a rainfall of about 22 inches, only 3½ inches percolated to a depth of 3 feet in the soil; and from 1869 to 1871, out of 25 inches, little more than 4 inches. The percolation through chalk is greater, but in the first period mentioned the average in the three years was only 5·20 inches.

Nor can it be too often repeated, that every gallon of water pumped and carried away from an absorbent district is so much abstracted from the flow of the streams of that district. There are of course some tracts of country—as for instance, on our own southern coasts—in which there are no surface streams, and the natural vent for the underground water is by springs along the sea-shore; but in inland districts the streams form an exact gauge of the excess of the rainfall over the water carried off by the processes of evaporation and vegetation. The streams being merely the overflows from the subterranean reservoir, it is evident that any artificial diminution of the water in the reservoir must, *pro tanto*, affect the streams; and even in those districts where the discharge is towards the sea, that discharge will be diminished in a similar manner. I have heard people speak of vast and inexhaustible stores of water, which have been laid up in the body of the earth for untold ages, and which have merely to be tapped to meet all the necessities of a crowded population; and I have heard others speak of springs as if there were some spontaneous process in nature by which water was produced in unlimited quantities. But all here will readily acknowledge that the water that is upon the earth beneath, and the water that is under the earth, derives its existence from no other source than from the heaven above.

Mr. J. T. Harrison's scheme for obtaining water by means of tunnels in the chalk of the Thames valley merely means that all the water derived from the tunnels will either be intercepted on its way to the river, or filter into the tunnels from the bed of the river itself. The flow of the Thames below will be diminished

by just the same amount of water as that abstracted by means of the tunnels.

I have, however, dwelt almost too long on this part of my subject, and will only add that an annual supply of 4 inches of rain will, from every square mile of country, give a daily quantity of nearly 160,000 gallons of water, which, at the rate of 32 gallons per head per diem, would suffice for a population of five thousand souls. A population of four millions, such as that of the metropolitan area, would therefore, if supplied from deep wells in the chalk, as some have gravely recommended, absorb the total water-supply of 800 square miles of country, or of an area one quarter larger than the county of Hertford, and the whole of the surface-streams over this large area would in dry years absolutely disappear.

I have already mentioned the fact that in many districts, especially those consisting of calcareous rocks, the underground waters have a tendency to form channels through which they pass, in order eventually to appear at the surface in the form of springs. The formation of these channels seems in part due to the power of water to dissolve the lime-stone rock through which it passes. Pure water, indeed, possesses but small solvent powers; but when it is charged with carbonic acid, which rain-water derives both from the atmosphere and from decaying vegetable matter in the soil, its powers are largely increased, and as a consequence the spring and well water in such districts is largely charged with carbonate of lime. In other districts sulphates and chlorides are often dissolved, sometimes to such an extent as to render the waters medicinal or quite saline in character and unfit for ordinary use. These chemical impurities impart to the water containing them the quality of hardness, which the waters flowing off the surface possess in a far less degree. These latter, however, are liable to hold a larger proportion of organic and vegetable matter either in suspension or in solution, and on the whole deep well water is probably the more palatable.

It is hardly within my province to speak about the processes which have been introduced for the artificial softening and purification of water, but I may mention the natural agents which to some extent produce these effects. Where for instance a wide and shallow lake intervenes in the course of a river, it will often be found that the water passing out is softer than that which enters the lake, some of the salts of lime which were held in solution having been deposited or absorbed by the vegetation in the lake. Weeds and fishes, although when dead they are sources of impurity,

yet when living are great purifiers of water, as it is on the impurities that they subsist. It would indeed be difficult for animal or vegetable life to be maintained in chemically pure water. The exposure of water to the action of air in its course down a river, especially where there are rapids and falls, has a great effect in the decomposition and removal of nitrogenous impurities. These, however, are subjects which will probably be dealt with by my friend Dr. Pole in the next lecture.

As an introduction to what has to follow, I have attempted to give you some slight outline of the natural laws which regulate the circulation of water from the sea through the air to the earth, until it again returns to the ocean. For details there are numerous authorities which may be consulted, such as the various Reports of the Rivers Pollution Commissioners, Mr. De Rance's "Water Supply of England," Mr. G. J. Symon's publications, and those of Professors Prestwich and Tyndall, Mr. Beardmore, Mr. Bateman, and others.

The principal points which, it appears to me, the Engineer should always bear in mind are these:—

1. That the higher the level and the nearer the sea, especially on our western coasts, the greater is the rainfall.

2. That in these high districts the rocks are, as a rule, more impermeable than in the low, and the supplies to the streams larger and more immediate.

3. That in the low-lying and eastern districts the rainfall is small, and the rocks for the most part absorbent.

4. That while providing means for receiving and dealing with the maximum amount of supply, reliance can only be placed on the minimum, and not on the average.

5. That though in the case of permeable soils the absolute minimum of percolation may be disregarded, yet that the average of three years seems to show that not more than 4 or 5 inches of the annual rainfall can safely be regarded as available for the supply of both the wells and rivers of the district.

6. That any water abstracted from wells in a permeable district is so much abstracted from the sources of the neighbouring streams, though in many cases it can be and is returned to them after use.

In addition, I may venture to suggest that while at no town in this kingdom would there probably be much difficulty in obtaining a supply of practically pure water sufficient for drinking and cooking purposes, there exists no physical necessity for watering the roads or flushing the sewers with water of the same pure quality.

My mission this evening does not, however, extend to questions of water-supply. It has been my task briefly to trace what may be termed the natural history of our springs and rivers, and I must leave the subject of how best to utilise their waters in the competent hands of those who are to follow me in this course of lectures.

On the motion of the President a vote of thanks was passed to the lecturer by acclamation.

# APPENDIX.

TABLE of OBSERVATIONS.

| — | Winter. | | | Summer. | | |
|---|---|---|---|---|---|---|
| | Rain. | Percolation. | | Rain. | Percolation. | |
| | | Soil. | Chalk. | | Soil. | Chalk. |
| 1854–55 | 9·32 | 2·45 | 3·45 | 12·66 | 0·19 | 2·30 |
| 1855–56 | 14·48 | 6·82 | 10·47 | 14·86 | 2·79 | 3·09 |
| 1856–57 | 11·96 | 3·72 | 7·19 | 14·11 | 1·11 | 1·32 |
| 1857–58 | 11·81 | 5·64 | 7·16 | 12·27 | 0·80 | 0·84 |
| 1858–59 | 9·64 | 0·09 | 2·69 | 18·31 | .. | 4·22 |
| 1859–60 | 16·49 | 9·27 | 12·44 | 20·40 | 3·16 | 8·94 |
| 1860–61 | 11·56 | 7·61 | 7·55 | 10·38 | 1·13 | 1·02 |
| 1861–62 | 12·63 | 7·42 | 8·19 | 14·37 | 2·39 | 1·77 |
| 1862–63 | 11·01 | 3·56 | 5·50 | 13·40 | .. | 0·19 |
| 1863–64 | 9·24 | 3·18 | 5·89 | 8·42 | 0·35 | 0·45 |
| 1864–65 | 10·93 | 3·42 | 3·55 | 12·60 | .. | .. |
| 1865–66 | 20·00 | 10·47 | 12·05 | 15·59 | 0·03 | 0·20 |
| 1866–67 | 12·60 | 4·64 | 6·97 | 14·37 | 0·18 | 1·39 |
| 1867–68 | 11·36 | 2·03 | 5·36 | 10·05 | 0·04 | 0·42 |
| 1868–69 | 17·58 | 7·64 | 11·21 | 12·80 | 0·02 | 2·00 |
| 1869–70 | 13·33 | 4·50 | 8·76 | 7·59 | .. | .. |
| 1870–71 | 12·54 | 2·08 | 5·35 | 16·09 | .. | 1·72 |
| 1871–72 | 11·25 | 4·65 | 9·50 | 14·44 | 1·00 | 2·70 |
| 1872–73 | 21·55 | 11·25 | 16·05 | 11·29 | .. | .. |
| 1873–74 | 8·91 | 1·86 | 4·40 | 10·71 | 0·05 | 0·65 |
| 1874–75 | 11·69 | 4·15 | 5·57 | 15·00 | .. | 3·46 |
| 1875–76 | 17·28 | 6·08 | 10·29 | 14·25 | 0·50 | 1·15 |
| 1876–77 | 20·69 | 10·13 | 11·77 | 13·74 | 1·04 | 1·60 |
| 1877–78 | 13·74 | 4·00 | 8·91 | 18·46 | 2·16 | 5·11 |
| 1878–79 | 14·62 | 5·75 | 7·94 | 25·09 | 6·94 | 12·82 |
| 1879–80 | 5·84 | 2·79 | 4·28 | 16·40 | .. | 3·20 |
| 1880–81 | 20·07 | 13·59 | 16·36 | 14·85 | .. | .. |
| 1881–82 | 14·82 | 6·24 | 11·38 | 16·52 | 0·48 | 2·64 |
| 1882–83 | 22·67 | 11·67 | 17·16 | 13·94 | .. | 0·33 |
| 1883–84 | 12·95 | 4·53 | 8·56 | 9·76 | .. | .. |
| | 412·56 | 171·23 | 255·95 | 422·72 | 24·36 | 63·53 |
| Average of thirty years | 13·752<br>14·091 | 5·707<br>0·812 | 8·532<br>2·118 | 14·091 | 0·812 | 2·118 |
| Yearly average | 27·843 | 6·519 | 10·650 | | | |

19 February, 1885.

SIR FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

# "Water-Supply."

By WILLIAM POLE, F.R.S., M. Inst. C.E.
Honorary Secretary.

## INTRODUCTION.

MR. PRESIDENT AND GENTLEMEN,—It was with considerable diffidence that I undertook to deliver this Lecture on Water-Supply. You all know that we have in our Institution some veterans who have acquired world-wide fame in this department of engineering; and it was not till I had been assured that there was no hope of getting any of them to undertake it that I would listen to the application. I am not, as they are, renowned for the construction of water-works; but it happens that, during almost the whole of a long professional life, I have been occupied more or less in the study and discussion of matters connected with water-supply, and I suppose it is on this account that the Council have done me the honour to apply to me.

And, in reality, my task is not a very difficult one; for, thanks to the great ability and the long experience of the masters of the craft, the modes of effecting water-supply have been pretty well settled. My chief duty is to give a very general view, without much detail, of the principles and practice that appear to have been established in this matter, and if I can succeed in doing this clearly, it is all I can desire.

The prospectus of these lectures gives the general title of "The Theory and Practice of Hydro-Mechanics." I have little to say about theory here, as the problems affecting water-supply works are chiefly the same as for mechanical and structural engineering generally.

In regard to the theory of hydro-dynamics, I may refer you to an able article lately published in the "Encyclopædia Britannica," by

a Member of our body, who has made this subject specially his own, Professor Unwin; and as you will shortly have the pleasure of hearing a lecture by this gentleman, he will probably give you some remarks on the point. I will only say a word as to the special problem of the flow of water along channels of various kinds.

There are certain simple and well-known formulas and tables which, by long experience, have been found fairly suitable for ordinary purposes. But later researches have shown that in many points they require amendment when a greater approach to accuracy is desired. These researches were made some years ago by two French engineers, Messrs. D'Arcy and Bazin; and the points they chiefly laid stress on were two.

In the first place, it had been usually assumed that the retarding force of the friction was independent of the nature of the surface of the channel. This was found to be an error, different materials requiring different coefficients.

And then, secondly, it was discovered that the relations between the velocities of the current at different parts of the section had not been correctly determined, and had values varying greatly under different circumstances.

I am not going further into these matters; they can easily be referred to if required. And having said this, I will proceed to the more practical views of water-supply.

In the admirable Introductory Lecture, we have heard explained the general phenomena by which the great element, water, is delivered on the earth for our use. We have now to enter on what is more strictly the province of the engineer in regard to water. We have to show how the stores of this invaluable substance can be, and are, made available for the use and convenience of man. This is done in many ways. The engineer has to provide and distribute supplies of water for the food and the various necessities of congregated populations. He has to make available the ample natural stores of mechanical water-power. He has to direct and control the natural flow of surface-waters, by operations of drainage and river-regulation. He has to take advantage of the fluid mobility of water, by using it to form highways of minimum traction in inland navigation. He has, moreover, to design floating vessels to travel upon water. And he has to provide for the safe and convenient communication of such vessels with the land, by harbours, docks, and piers.

All these works in the aggregate, with their almost infinite

expanse of detail, constitute the great branch of our profession called hydraulic engineering; and this will form the subject of the remaining lectures of the present course.

But before I enter on my humble share of the work, I should like to mention an interesting historical fact, which I think is not generally known, namely, that it is especially to hydraulics that civil engineers are indebted for their origin and existence as a separate and independent profession.

The term "engineer" was originally applied to military men. Building-works in civil life were constructed by the architect, who in all ages has been a well-recognised practitioner.

A century or two ago, however, a new and peculiar demand arose in this wise. The great rivers in the north of Italy had relapsed, by neglect, into a very bad state, giving rise to disastrous inundations. The nation became alarmed, and the most learned scientific men of the day were consulted as to what should be done. This gave rise to a series of valuable theoretical and practical studies, which are of great historical interest, as having formed the basis of hydraulic engineering. The knowledge spread rapidly throughout Europe, and gave a great impulse to hydraulic operations generally.

But there was now a want of competent men to execute them. The architects found these new studies foreign to their own proper business; and so a new class of practitioners sprang up for hydraulic works; with which soon became associated other works of analogous character. Such a class required a new name, and this was easily found. It was noticed that the kind of work undertaken by these new practitioners corresponded to that allotted to the engineers of the military service; and the new profession adopted the same title, prefixing, however, the epithet "civil," to indicate that they were civilians, and so to distinguish them from their military brethren.

Hence the origin of the present term "civil engineer," an origin which, as I have said, was due entirely to the cultivation of hydraulic science, and its application to works of hydraulic construction.

The expression "Water-Supply," in its general sense, may have a wide interpretation. It may refer to supplies of many kinds, and for many different objects. But there is one kind of Water-Supply which stands pre-eminent and before all others, namely, the supply to the inhabitants of towns. It was this that was probably in the minds of your Council when they drew the

title of this lecture, and I shall not err in directing attention specially to it.

I need hardly enlarge on the value of water. I suppose it is the most important natural substance known, and the most indispensable for maintaining the present order of things in organic life. The old Greek sentiment, Ἄριστον μὲν ὕδωρ, was a natural prompting; some ancient philosophers supposed water to be the primordial element of which every living being was composed; and this is so far true, that water forms a very large part of the bodies of plants and animals, and constitutes, either simply or in combination, the greater portion of their food. The need of water for the life, health, comfort, and occupations of mankind, is patent to everybody; and hence the provisions for a due supply of it, of proper quality, in ample quantity, and in a convenient manner, become an absolute necessity of civilization.

## History.

In the earliest times people helped themselves from the nearest brooks or streams. But this hand-to-mouth process was only available in certain places; and as it was observed by unmistakable signs that the superficial strata of the earth often contained water, the idea occurred to some ingenious person that this water might be got at by simply making a hole in the ground, or, in other words, "sinking a well." Wells are mentioned as sources of water-supply in the oldest records we have, and the art of sinking and working them had arrived, in early ages, at great perfection.

But still even wells could not be got everywhere, and as populations increased, some further extension of water-supply became necessary. The simplest plan of meeting this want was to carry the water in suitable vessels from the stream or the well where it was found, to the places where it was required. And primitive as this plan appears, it has lasted into quite modern days. I recollect, when I lived as a boy in a large English town, seeing water carried about for sale, in cans with a yoke, as milk is often carried here; and even a few years ago, being in a fashionable watering-place for my health, I was advised by the local doctor not to use the town supply, but to drink the water of a neighbouring spring, brought round in a barrel on wheels every day.

But the more appropriate device soon presented itself of conveying water from distant sources by means of conduits, slightly inclined, so as to allow the liquid to flow along them by its own

gravity. This was, indeed, only a direct artificial imitation of natural streams. It is very old, and is mentioned by Homer.[1] It began in leading streams along the surface of the ground; but it ultimately developed into the supply of towns by the ancient aqueducts with which you are all acquainted, and which culminated in the magnificent water-supply of the Eternal City.

These aqueduct-conduits usually terminated in public fountains within the town, from which the inhabitants could, without much trouble or inconvenience, get the water carried to their dwellings. Everybody who has been in Rome has admired the fountains there, and they are very common in continental cities generally.

The next great step in municipal water-supply, namely, that of delivering the water into the houses of the inhabitants, is of comparatively late introduction. It depended on a considerable degree of mechanical advancement; for to carry out such a system it was necessary to convey the water in pipes under pressure. There is no doubt that pipes of earthenware, of wood, and of lead, were used by the Romans to some extent, but they were very imperfect, and nothing existed in the shape of such fittings as would be necessary for house-supplies. The first application of the house-supply that I can hear of was in London, brought about by the historically celebrated waterworks of Peter Morice, the Dutchman, established at London Bridge in 1582. Here water-wheels were erected which pumped the water from the Thames, and forced it along pipes laid through the streets, to the places where it was required; and it is clearly stated by the well-known antiquarian authority Stowe, that "the Thames water was conveyed into men's houses by pipes of lead."

When this convenient system was once established, it was easily seen that the more ancient conduit-supplies might also be adapted to it, by bringing the water into a reservoir at a high level, the hydrostatic pressure from which would answer the same purpose as the pumping pressure in the former case. This was done in the New River supply, brought into London in 1613.

Here, therefore, we have the two types of pumping and gravitation supplies on which all succeeding works have been modelled, with only improvements in detail.

The original London street-pipes were, if small, of lead, and, if

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[1] *ὡς δ' ὅτ' ἀνὴρ ὀχετηγὸς ἀπὸ κρήνης μελανύδρου*
*ἀμφυτὰ καὶ κήπους ὕδατος ῥόον ἡγεμονεύει.*—*Iliad*, xxi. 257–8.

"So when a peasant to his garden brings
Soft rills of water from the bubbling springs."—*Pope.*

large, of wood. About the middle of the eighteenth century cast-iron pipes were used, but their high price prevented their general adoption for a long time; it was not till about 1810 that this material may be said to have come into common use; and it was only after that date that the water-supply of towns could take any great development. This development did follow, in the attainment of a higher pressure, and generally a better and more ample supply; and the improvements have been continually progressing to the present day.

Before considering the various modes of effecting the water-supply to towns, it is necessary to say a few words on two points of a general nature which bear alike on all modes of supply. These are, the quality of the water, and the quantity of it which is likely to be required.

## Quality of Water.

The quality of water to be supplied to a town is a matter of great importance. This is a subject properly belonging to chemistry, and the aid and advice of a professional chemist must always be called in upon it. But still, any engineer concerned in a water scheme would be at a manifest disadvantage, if he did not know enough of the matter himself, to enable him at least to form a preliminary judgment on the sources of supply.

Rainwater, as distilled in the clouds, may be considered as practically pure; but it seldom happens that it can be collected and stored without having undergone some contamination. However directly we may attempt to catch it, it will be liable to take up some foreign ingredient from the collecting surfaces, and if it percolates through the earth to springs and wells, it will gather a still greater amount of foreign matters.

The impurities taken up may be classed under three heads:

I. Substances mechanically suspended in the water.

II. Mineral substances chemically dissolved in the water.

III. Dissolved organic impurities.

This classification is not strictly definite in a chemical sense, but it is convenient as regards the importance of the impurities in the view of the engineer.

I. *Suspended impurities* are chiefly found in the water of rivers and streams. They come from the water washing over earth, clay, mud, sand, refuse, &c., the finer particles of which it carries away, and holds in mechanical suspension. "Dirty water," "turbid water," "muddy water," are only other names for water containing

matter in suspension. This kind of impurity is of the least importance to the engineer, seeing that it admits of thorough removal by easy means. Two operations are used for this purpose, viz., subsidence, and filtration.

Subsidence is simply allowing the water to rest, when the grosser and heavier particles, which are only kept in suspension by motion, will fall down. Everybody who has seen the Lake of Geneva will remember that the Rhone, which flows in at the head in a muddy stream, issues out at Geneva as clear as crystal. The lake is simply a vast subsiding reservoir.

It is impossible to make ordinary subsiding reservoirs as effective as Lake Leman, but they will do a great deal of good; and down to the year 1829, they were the only means used for purifying water-supplies. The defect of them is, that some of the suspended matters are so light that they will not subside without much more time than can be allowed; and to remove these matters, an additional process is used, namely, filtration.

This is exactly analogous to ordinary filtration, the water being passed, at a slow rate, through a porous material, of such fine texture as to stop the suspended particles, and allow only the clear fluid to pass through.

This contrivance, as applied to water-supplies on a large scale, originated in London in 1828. A Royal Commission had reported that the Thames water supplied to the metropolis was very dirty and objectionable, and the late Mr. James Simpson, the engineer of the Chelsea waterworks, determined to try what could be done to improve it. It was known that fine sand was a good and efficient material for effecting filtration; but the difficulty was how to apply it on a large scale, so as to render the cleansing of the filter reasonably practicable. It occurred to him that if the water was allowed to pass downwards through a bed of fine sand, held up by underlying layers of coarse gravel and stones, the dirt would not penetrate into the mass, but would be stopped at its upper surface; and in this way the whole cleaning operation necessary would be to scrape this surface off to a slight thickness, and, when it had become too much diminished, to put fresh sand on. The first waterworks filter on this plan, of one acre area, was set to work by Mr. Simpson, at the Chelsea Waterworks, in 1829. It was found to work well, and has furnished a model, with scarcely any material change, for all subsequent time.[1]

[1] Complete drawings of Waterwork filters will be found in the Minutes of Proceedings Inst. C.E., vol. xxvii., p. 20.

The filtering action has been above described as purely mechanical, *i.e.*, as arresting the suspended particles and nothing further. But careful observations on the process have lately led to a belief that it exercises some chemical purifying action on the dissolved organic matter. The nature of this action is at present obscure. It is supposed, however, that some kind of oxidizing process may be encouraged in the passage through the pores of the material; and it is certain that by the expedient of intermitting the filtration, so as to allow of the aeration of the material, this effect may be rendered much more active.

It is important that in ordinary sand filtration the process should not be hurried. Slowness promotes good purification, and the rate of passage through can be regulated by the head of water over the sand. The result of experience with London water is, that the rate of passage should not exceed 2½ gallons per hour through each square foot of area. At this rate each million gallons a day will require 16,700 square feet of filter at work, and allowance must be made for one filter-bed being always out of use for cleaning.

In some peculiar cases, special materials have been used instead of sand. It has been found, for example, that certain compounds of iron have a remarkable effect in destroying organic matter. The town of Wakefield has been for a long time supplied from the River Calder, the water being so impure, that a letter written with it was published by the Rivers Pollution Commissioners. Yet the unwholesomeness of this was checked by filtration through a magnetic carbide of iron. Another case has been lately described to this Institution by Mr. William Anderson,[1] where the water supplied to Antwerp was purified by Bischoff's spongy iron in the same way.

The two operations, subsidence and filtration, are usually combined, the advantage being that the previous extraction of the grosser particles gives the filters less to do, and allows them to work longer without cleaning.

II. But, though the water may be clear and bright, it may contain a different class of impurities, namely, *mineral substances chemically dissolved* therein, that cannot be removed by filtration.

Such dissolved matters exist in water sometimes in great extent and variety, forming what are called mineral or medicinal waters. These, however, are altogether exceptional; there is practically only one substance which affects water likely to be used for town supplies, and that is lime. Calcareous rocks occupy, it is said,

[1] Minutes of Proceedings Inst. C.E., vol. lxxii., p. 24.

four-fifths of the earth's surface, and as their material is, to a certain extent, soluble, the waters percolating through them take lime up in their passage. Hence lime is found largely in wells and springs; and as superficial streams are almost always fed partially by springs, rivers contain lime also. The River Thames, for example, after perfect filtration, contains about 15 to 20 grains of solid matter in solution, which is almost entirely composed of salts of lime.

These salts communicate to the water the peculiar quality called *hardness;* soft water makes a lather freely, but hard water has a disposition to decompose or curdle soap, by the combination of the lime with the alkali.

There has been a great deal of discussion as to the comparative merits of hard and soft water for town supplies, and the subject was thoroughly investigated by the Royal Commission on Water-Supply in 1869,[1] to which I had the honour of being secretary. I may give you in a few words the result of their inquiries.

There are two uses of water to be considered—for drinking, and for washing and manufacturing purposes.

For drinking: there have been contradictory opinions as to the effect of hard water on health. Some say it causes calculous diseases; others say it promotes the formation of a healthy bony frame. But when the evidence is examined, there is no reason whatever to suppose that a moderate hardness, like that in London, is in the least degree prejudicial.

And it has advantages in many respects; the water is pleasant to the taste, and by its less solvent power it is free from action on lead, which is often dangerous with very soft water. It is also less absorbent of gases and organic impurities, and it keeps better.

For washing and manufacturing purposes, however, the advantages of soft-water are undeniable, and in towns where the uses of water for these purposes largely predominate, every effort should be made to procure a soft-water supply. Glasgow and Manchester are striking examples of how this may be done; and it is fortunate that the great manufacturing districts of England are so situated as to render soft-water supplies easily available. But from the great prevalence of the limestone formations, this is not possible everywhere; and where, as in London, a supply of moderate hardness is close at hand, it is a comfort to know that it may be used without material disadvantage.

I say of *moderate* hardness; but it often happens that the

[1] Report of this Commission, pars. 156 to 176.

hardness is not moderate. The water from chalk wells, for example, sometimes contains 30 to 50 grains of lime-salts per gallon, when the use of the water may become very troublesome.

But nature has provided a remedy for this, inasmuch as such water may be easily softened. The salts of lime are generally carbonates and sulphates, the former predominating. Now carbonate of lime is very slightly soluble in pure water, only to the extent of about 2 grains in a gallon. The reason why natural water often contains so much more is the presence of free carbonic acid, which acts as a solvent, and enables the water to take up the extra quantity.

If, therefore, we can, by any means, drive away this carbonic acid, the superfluous carbonate of lime will be precipitated, and the water will be softened.

This may be effected in several ways:—

1. By exposure of the water to the air, when the carbonic acid flies off spontaneously. Open channels conveying very hard water are often found to collect deposit from this cause, a striking example of which may be seen in the celebrated ancient aqueduct of the Pont du Gard, near Nismes. Stalactites and stalagmites in limestone caverns are formed in the same way, as are also the deposits in what are called petrifying springs.

2. By boiling. Every washerwoman knows that hard water may generally be softened by boiling, which drives off the carbonic acid rapidly. The deposit in boilers, so well known and so troublesome, is a result of this action. Many calcareous waters contain other salts of lime besides the carbonate, and these boiling will not remove. Hence it is customary to speak of the *temporary* as contrasted with the *permanent* hardness, the latter being the hardness which remains after boiling.

3. Another way of treating hard water is by adding simple lime, in its caustic state. This seizes the free carbonic acid in the water, forming a carbonate, when both this and the carbonate already in the water are precipitated, and may be removed. It is curious that the hardness of water, which is due to lime, should be diminished by adding more lime; but the explanation is very clear.

This softening process, by means of lime, is due to the late Dr. Clark of Aberdeen, who urged its adoption very warmly. In 1850 I assisted, under his direction, at some trials at the Chelsea Waterworks, to judge of its applicability to London water. We found it could easily be done, but it was expensive, and the general opinion was that the advantage was not worth the cost.

It has, however, been successfully applied elsewhere. In the

same year Mr. Homersham adapted it to some large print-works, and he afterwards put it in practice at Plumstead, at Caterham, and elsewhere. One of the latest and most successful applications has been made by Mr. Bateman at the Colne Valley Works, near Watford. The water, which comes from chalk wells, has naturally about 18 to 20 degrees of hardness, and is softened down to 5 degrees.

Some modifications of this softening process have lately been contrived. The most important one has been devised by Mr. Porter, with the view of doing away with the deposition in reservoirs, which is not only expensive, but takes a long time. He agitates the mixture, so as to produce quickly and thoroughly the necessary chemical change, and then passes it through a filtering press, which retains the precipitate, and allows the clear water to be forced through. It is also worthy of mention that Mr. Hallett, Mayor of Brighton, has shown that by very simple and inexpensive apparatus a softening process may be adopted in private houses, wherever thought desirable.[1]

III. The third kind of impurity is *organic impurity*, and this requires very careful consideration. But it will be convenient to postpone the remarks upon it till we come to speak of river supplies, in which it chiefly prevails.

## Quantity of Water required.

We now come to the other preliminary point. Before an engineer can take proper steps for the supply of a town he must form an estimate of the quantity of water he will require.

The water consumption in a town varies according to the occupations of its inhabitants, and the nature of the industries carried on, as well as, in some degree, on the habits of the people in regard to the use of water.

The quantity actually required for domestic consumption, including a fair allowance for general household purposes, for water-closets, and for ordinary ablutions, is probably not more than about 10 gallons per head per diem. But in addition to domestic consumption, supplies have to be provided for gardens and stables, manufacturing and trade purposes of many kinds, baths and wash-houses, public fountains, watering streets, flushing sewers, and extinguishing fires. The quantity for these purposes will vary considerably, say from 5 to 10 or more gallons per head per diem.

[1] Transactions of the Brighton Health Congress, 1881, p. 295.

As a general rule, however, if the town contains nothing likely to make the consumption abnormal, it is usual to estimate that about 25 gallons per head per diem will be, or at least ought to be, a sufficient supply for all purposes.

I say ought to be, because there enters into this question a very important element, namely waste. I shall have to speak about this hereafter, but I may say here that as a general principle the supply of more water in a town than is reasonably required for the health, comfort, and occupations of its inhabitants, and for the general sanitary public requirements, is an evil, and ought to be discouraged and repressed. Water is a very expensive thing to provide, and its excessive use not only wastes money, but does positive mischief by increasing the difficulty of carrying it away. An engineer, therefore, in designing waterworks has a right to anticipate that reasonable care will be exercised to keep down the consumption to what is actually necessary.

At the same time he must not stint his preparations; for in designing works for water-supply, provision ought always to be made for increase of population. There are few towns of importance that do not extend their limits from year to year, and the cases where difficulty has occurred, from insufficient water-provision being made for these extensions, have been frequent and troublesome.

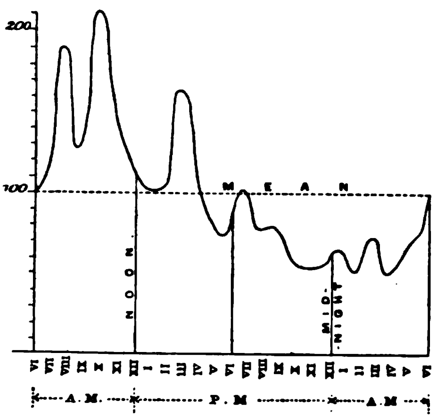
It is important to remember that the consumption is not uniform. It has a considerable fluctuation at different hours of the day, and also at different parts of the year.

The daily fluctuation is caused by the variations in the demand for water at different hours, which is very considerable. The following Table is the result of observations carefully taken under the direction of Mr. Ayris, who has kindly allowed me to make use of them for this lecture.

It is not easy to account for all the irregularities, but the general result is that, as might be expected, the consumption in the daytime much exceeds that during the night, amounting at one time to above twice the average rate. This is about 10 A.M., when the domestic use of water may be supposed to be the most active.

PROPORTIONATE CONSUMPTION of WATER at DIFFERENT HOURS of the DAY in a COUNTRY TOWN of ABOUT 50,000 INHABITANTS, SUPPLIED UNDER the SYSTEM of CONSTANT SERVICE.

AVERAGE of the SIX WORKING DAYS.




Hourly variation of the rate of Consumption of Water under constant supply.

| | Proportionate Consumption in the Hour, the Average over the whole day being 100. |
|---|---|
| From 6 to 7 A.M. | 104 |
| " 7 " 8 " | 193 |
| " 8 " 9 " | 128 |
| " 9 " 10 " | 215 |
| " 10 " 11 " | 161 |
| " 11 " 12 " | 122 |
| " 12 " 1 P.M. | 104 |
| " 1 " 2 " | 102 |
| " 2 " 3 " | 166 |
| " 3 " 4 " | 130 |
| " 4 " 5 " | 85 |
| " 5 " 6 " | 74 |
| " 6 " 7 " | 102 |
| " 7 " 8 " | 78 |
| " 8 " 9 " | 81 |
| " 9 " 10 " | 61 |
| " 10 " 11 " | 55 |
| " 11 " 12 " | 54 |
| " 12 " 1 A.M. | 66 |
| " 1 " 2 " | 52 |
| " 2 " 3 " | 74 |
| " 3 " 4 " | 52 |
| " 4 " 5 " | 65 |
| " 5 " 6 " | 74 |

The fluctuation in the consumption at different periods of the year will be shown by the following Table, taken from Colonel Sir Francis Bolton's published Reports:—

CONSUMPTION of WATER in LONDON DURING EACH MONTH of the YEAR 1883.

| | Millions of Gallons per Diem. |
|---|---|
| January . . . . . . . . . . . . . | 133·5 |
| February . . . . . . . . . . . . | 130·8 |
| March . . . . . . . . . . . . . | 132·9 |
| April . . . . . . . . . . . . . | 139·0 |
| May . . . . . . . . . . . . . | 143·6 |
| June . . . . . . . . . . . . . | 159·5 |
| July . . . . . . . . . . . . . | 159·1 |
| August . . . . . . . . . . . . . | 159·8 |
| September . . . . . . . . . . . | 154·1 |
| October . . . . . . . . . . . . | 146·5 |
| November . . . . . . . . . . . . | 142·7 |
| December . . . . . . . . . . . . | 138·6 |
| Mean of the year . . . | 145·0 |

This shows an excess, over the average, of about 10 per cent. in the hottest months, and a deficiency of about the same in the coldest.

Taking these two Tables together, it will be seen that it is necessary, in all towns on constant supply, to provide carrying capacity much larger than is due to the average consumption. For example: suppose the average consumption over the whole year to be 1,000,000 gallons a day, then the average in the summer months will be 1,100,000 gallons. And in some hours of each day in those months the consumption will be at the rate of about 2,350,000 gallons per day, for which the mains must accordingly be prepared.

### General Sources of Water-Supply.

I now go on to speak of the various modes of obtaining water-supplies. There is only one original source, rain; but there are several varieties in the modes by which the rainfall is made available. These are:—

1. *Direct collection.*—We may catch the rain-water as it descends close to the places where we want it, storing it up in suitable receptacles.

2. *Gathering Grounds.*—We may choose a surface of land, and collect the rain-water falling thereon.

3. *Rivers.*—We may take water by pumping from a river of sufficient magnitude, flowing along low ground.

4. *Wells or springs.*—We may draw upon the stores of water contained in subterranean strata, by sinking wells; or we may collect the same water as it issues spontaneously in springs.

We may say something on each of these plans.

### Direct Collection of Rainfall.

First, we may catch the rain as it descends, on the spot where it is wanted. A rain-water butt, collecting the rain from the roof of a house, by gutters and pipes, is a very common thing; and the same plan is often advantageously carried out in large isolated establishments, such as gaols, unions, asylums, &c.[1]

In Venice the greater part of the water-supply of the city is obtained in this way. Many people will recollect two handsome artistic well-curbs in the court of the Ducal Palace. These are openings into underground reservoirs made to receive and store the

[1] 1,000 square feet of horizontal roof surface, catching 24 inches of rain per annum, will, if none of the water is lost, yield 34 gallons per diem.

whole of the rain that falls on the buildings; and there is an ingenious arrangement by which the water is made to pass through a filter before it gets into the well.

But it is in India and other tropical climates that the direct collection of rainfall has the widest application. In these places a very large quantity of rain descends during the monsoon, *i.e.*, four months of the year, whereas during the other eight months not a drop falls. Rivers are only available in their immediate locality, streams become in the dry season mere sandy beds; wells are only locally and partially efficient, and the great trust is in the system of tanks. These are open excavations made in the ground in great numbers and often of large size, which become filled by direct rainfall during the monsoon, and store up the water for use during the rest of the year.

### Gathering Grounds.

But the more common way of making a direct appropriation of rainfall is by collecting it on the surface of a tract of land, which is called a gathering ground.

To illustrate how this is done we will imagine a tract of land lying high in a hilly district, and on which a fairly large quantity of rain falls. By reason of the natural slope of the various portions of this area, the water will run off it in little rills and rivulets, which will ultimately combine into one principal stream, draining the whole area. Hence, by taking possession of, and utilizing this stream, we in reality collect and utilize the rain-water falling over the whole of this drainage area.

This is done by forming a *reservoir* upon the stream in question. The stream will naturally flow in a little valley, and, by choosing a convenient place, and constructing an embankment across this valley, the waters of the stream will be dammed back and impounded in the trough of the valley above the embankment, and so will form a reservoir, containing a store of water. This store is made available for the supply of a town, by simply laying down a conduit from the reservoir to carry it to the place where it is required. When the reservoir is full, the superfluous water will overflow by a waste-weir and conduit (called a bye-wash) down to its original channel.

This mode of obtaining water-supplies is very common in hilly districts, and numbers of large towns, particularly in the manufacturing districts of Yorkshire and Lancashire, are supplied in this way.

The formation of large reservoirs of this kind is a very responsible and difficult thing, only to be undertaken by engineers of great experience and sound judgment. The first object is to secure the absolute safety of the dam, seeing the frightful consequences that must ensue if it should give way, suddenly letting loose such an enormous mass of water, from a great height, down upon the country below. When the reservoir is full the pressure upon the dam is very great, and although, considered as a mass, it may be stable enough, yet the water by penetrating among its loose materials may gradually endanger its cohesion; or the natural ground against which it is formed may be treacherous, and give way.

Such failures have occasionally happened, one of the most disastrous of them being the bursting of the dam of Dale Dyke Reservoir, above Sheffield, in the year 1864. By this accident above 100,000,000 cubic feet of water were suddenly let loose, rushing with tremendous violence down a narrow valley and through the town of Sheffield, and causing the loss of two hundred and fifty lives, with the destruction of property to the amount of hundreds of thousands of pounds. No wonder that the inhabitants of valleys in which water-supply reservoirs are situate should feel anxious about their construction, and about the competence and skill of their builders.

Then the reservoir must not only be safe but it must be sound, *i.e.*, perfectly water-tight. Leaks must be prevented, not only in the artificial dam, but also in the whole interior surface of the reservoir, the strata in these mountainous countries being often fissured and treacherous.

It is impossible for me to offer any explanation of how an engineer is to produce a good, safe and sound reservoir, seeing that in the first place it is not the purpose of these lectures to enter into engineering details; and secondly that the difficulties to be encountered are so varied in their nature, and depend so much on local circumstances, as not to admit of any such notice as would be practicable here.

*Supplies from Lakes.*—Some large towns are supplied from natural lakes. This mode of supply is in reality the same as that just described. The lake is fed by streams from a gathering ground, and it is in fact only a reservoir, made by nature instead of by art. Or to put the comparison in another way, a reservoir is only a lake made by art instead of by nature. When, however, a lake is used for water-supply, something must be done to it artificially to fit it for its work. The popular notion that, given a lake, you may draw water without limit from it, as you might out of the sea, is a

delusion. The essence of a reservoir is that it is a store of varying content:—it can be filled when the supply comes to it, and when there is no supply it can be drawn down. Now a natural lake has usually a level pretty nearly uniform. To fit it for water-supply this must be altered; it must be capable of being drawn down for the use of the district in times when there is no rain. This being done, we may consider the two cases identical.

*Yield of Gathering Grounds.*—The quantity of water which may be obtained from gathering grounds is a very complicated and difficult study. At the same time it is exceedingly important, for on the accuracy of its determination must depend the sufficiency of the supply to the inhabitants of a town. Cases have unfortunately not been uncommon where towns supplied from gathering grounds have been in great distress for water. In the long drought of 1868, Manchester, Bradford, Halifax, Sheffield, Preston, and many other towns, suffered severely, and the same thing occurred again last year, almost amounting in some places to a water famine.

The causes lie in the uncertainties of the meteorological conditions in our pre-eminently uncertain English climate, and they necessitate a most careful study of the problem by the engineers and promoters of water-undertakings.

We can ascertain the area of the gathering ground with the greatest accuracy. But the difficulties arise in estimating the quantity of *rainfall* we can get off it. For a long time the information gathered about this most important element of engineering calculation was very scanty. But of late years, thanks to the indefatigable labours of Mr. Symons, there have been collected, in his annual Reports on British Rainfall, a series of data of the most useful and valuable character.

The rainfall varies exceedingly at different times and in different places.

As to the variability at different times, I shall have hereafter to speak more fully.

To illustrate the variation in different places I may refer to an admirable map of the rainfall in the British Islands, prepared by Mr. Symons, which is published in the Sixth Report of the Rivers Pollution Commission, 1874. This shows that the annual rainfall in different parts of the country varies from 25 to 75 inches. But the extreme variations run much higher. For, taking single stations in 1883, the rainfall at the Stye in Cumberland was 190 inches; at Clacton-on-Sea, in Essex, it was only 18·7 inches—one ten times greater than the other.

These places lie wide asunder, but even in the same locality the rainfall will vary materially in sites only a short distance apart. And hence it is always desirable that, before any important proceedings are taken, the rainfall upon a tract of ground proposed to be used as a catchment-area should be ascertained, as far as possible, by direct observations upon the ground itself.

Suppose, then, we have taken such observations, say for a year, and suppose for example we find that the total annual rainfall over the area of our gathering ground amounts to 44 inches. Our first difficulty is that we cannot gather, for storage and use, anything like the total quantity of rain that falls. There is always a loss, which occurs in several ways.

In the first place, a part of the water will be returned to the heavens by evaporation; then another portion will be absorbed by the vegetation growing on the land; and, thirdly, another portion will percolate through pores and fissures of the earth, to enter subterraneous strata, and find its way out at a distance in springs.

Now these three sources of loss vary exceedingly under different circumstances, and at different times. They are all naturally greatest in hot and dry weather. A shower occurring at such times will often contribute nothing at all to the reservoir, whereas when the atmosphere is cold and damp, and the ground already wet, nearly the whole may become available.

The loss by percolation will vary materially according to the nature of the geological formation of the district. In chalk districts, for example, the whole rainfall is often absorbed into the earth, there being no surface streams whatever; whereas on compact rock formations the percolation may be almost nothing.

And then much depends on the inclination of the surface. If the ground is very flat the water will run off slowly, and will have more time to evaporate. In steep ground it will rush down rapidly into its receptacle.

In the face of these irregularities it would be impossible to give any accurate rules. All that can be done is to form some general notion of the results of experience.

Dr. Dalton, an eminent meteorologist, estimated that, taking the whole of England, only about one-third of the rainfall found its way into the sea, and this is estimated to be about correct as regards the Thames. But in mountainous districts the proportion of the rainfall flowing down the streams is greater, being often one-half or two-thirds, and sometimes even more.

It is usually considered more correct not to assume the losses

as proportionate to the rainfall, but to estimate them at a fixed quantity, whatever the rainfall may be.

This quantity will vary from about 12 to 18 inches per annum, according to the nature of the ground. Steep ground of compact rock will give the minimum, flat ground of more permeable rock the maximum deduction, as in the basin of the Thames, where the rainfall is about 27½ inches, and the loss is about 18 inches.

Hence out of our 44 inches assumed rainfall we must make this deduction before we can estimate the quantity of water available. For the sake of example, call this deduction 14 inches. This will leave 30 inches in the year available for use. Having got this, it is only a matter of simple arithmetic to calculate, knowing the area of the catchment ground, how much water we can get in that year.

There is a very simple rule for this:—

If $R$ = rainfall in a given year in inches;
$E$ = estimated loss by evaporation, &c., in inches;
$A$ = area of gathering ground in acres;

then

$$\text{Cubic feet of water per annum} = 3{,}630\,A\,(R - E),$$

or

$$\text{Gallons of water per diem} = 62 \cdot 15\,A\,(R - E).$$

But now we come to another complication, which leads us to consider the use of the reservoir.

During the year that we have taken the rain will fall irregularly; some months will be wetter and some will be drier. But the supply must be uniform or nearly so, and hence the reservoir must be of such size as to equalize the quantity, storing sufficient water in the wet months to tide over the drier ones. To illustrate this I may take an example out of Mr. Symons's Tables:—

RAINFALL at BRECKNOCK in SOUTH WALES for EVERY MONTH in the YEAR 1883.

| | Inches. |
|---|---|
| January | 7·06 |
| February | 10·19 |
| March | 1·67 |
| April | 1·20 |
| May | 2·22 |
| June | 5·14 |
| July | 3·73 |
| August | 1·25 |
| September | 6·04 |
| October | 5·81 |
| November | 5·55 |
| December | 1·88 |
| Total for the year | 51·74 |
| Mean monthly fall | 4·31 |

I have calculated what size of reservoir would be required to equalize these irregularities, so as to yield day by day a quantity of water equal to the average of the year, and I find for this purpose no less than about one hundred days' storage room would be required.

But there is another and a greater complication. In our simple hypothetical example we have assumed that we get, by our rain-gauges, the amount of rain falling in a single year. But this is only very imperfect information, seeing that the rainfall varies materially in different years. In some districts the variation is enormous. At Windermere, where the average of twenty-two years gave 79·85 inches, it sometimes reached 116·26 inches, and sometimes went down to 47·24 inches. But the worst feature of the variation is that there will sometimes occur several consecutive dry years.

Mr. Symons, in his report for 1882, has given a valuable Table illustrating this. He has collected, with vast labour, the records of rainfall at forty-five stations, during forty-three years. I may give the following as an example:—

ANNUAL RAINFALL at UCKFIELD in SUSSEX, for FORTY-THREE YEARS.

| — | Inches. | — | — | Inches. |
|---|---|---|---|---|
| 1840 | 22·30 | | 1864 | 23·48 |
| 41 | 36·30 | | 65 | 38·97 |
| 42 | 24·60 | 6 years average 24 in. | 66 | 33·79 |
| 43 | 30·09 | | 67 | 30·48 |
| 44 | 23·37 | 4 years average 22 in. | 68 | 30·51 |
| 45 | 23·03 | | 69 | 28·57 |
| 46 | 25·11 | | 1870 | 24·99 |
| 47 | 17·58 | Minimum. | 71 | 25·64 |
| 48 | 38·03 | | 72 | 38·64 |
| 49 | 29·33 | | 73 | 30·06 |
| 1850 | 28·62 | | 74 | 24·65 |
| 51 | 24·26 | | 75 | 29·02 |
| 52 | 50·55 | Maximum. | 76 | 33·37 |
| 53 | 31·70 | | 77 | 39·58 |
| 54 | 23·15 | | 78 | 31·25 |
| 55 | 23·80 | | 79 | 33·00 |
| 56 | 33·59 | | 1880 | 31·79 |
| 57 | 31·74 | | 81 | 33·05 |
| 58 | 19·36 | | 82 | 35·90 |
| 59 | 33·48 | | Mean of the 43 years | 30·08 |
| 1860 | 42·46 | | | |
| 61 | 28·35 | | | |
| 62 | 30·01 | | | |
| 63 | 25·74 | | | |

It will be seen that while the average of the forty-three years is a little over 30 inches, the annual fall sometimes reaches above 50 inches, and sometimes is as low as 17½ inches. Moreover, there were six years together when the average annual fall was only 24 inches, and four years together when it was only 22 inches.

It will be easily inferred from this, that a single year's datum of rainfall, which we have assumed in our previous example, will be of no use. It may have been a wet year or a dry year, or anything between. We must have, for our gathering-ground, data of the rainfall over a large number of years, embracing, if possible, all the variations of wet and dry.

How, then, are we to treat these data when we get them? We can of course deduce from them an average rainfall for the whole series. But this also is no proper guide, unless upon the condition that we can store over all the excesses of the wet years, to supply the deficiencies of the dry years.

Now I have taken some trouble to get a rough notion what size of reservoir we ought to have to equalize the forty-three years' rainfall shown in the above Table; and I find it would require a store of something like 900 days' supply. It is altogether unreasonable and impossible that a waterworks-undertaking could be burdened with such a monstrous construction.

Mr. Hawksley has often urged this with great force. He points out that however large, in reason, the reservoirs may be made, in wet seasons they will be full; and as floods come down chiefly in wet seasons, they will then simply run to waste down the bye-wash; —they cannot be stored;—and as these floods help materially to swell the average, this average cannot be obtained from the reservoirs.

Mr. Hawksley gives, as the result of his long study of the question, and great experience, that it is impossible practically to spread the equalization over a longer period than three years. And for the sake of safety, the three years taken for calculation must be the three driest years that come together.

Mr. Symons has deduced from his large Table some general results which appear to prevail; and they agree fairly well with data laid down by Mr. Hawksley in 1868, before the Duke of Richmond's Commission.

It is found that the wettest year will have a rainfall nearly half as much again as the mean.

The driest year will have one-third less than the mean.

The driest three consecutive years will each have one-fifth less than the mean.

Or, more exactly, if $R_m$ = mean annual rainfall over a long series of years, then

Rainfall in the wettest year $= 1 \cdot 4$ to $1 \cdot 5 \times R_m$.
Rainfall in the driest year $= 0 \cdot 63$ to $0 \cdot 67 \times R_m$.
Mean of the driest three consecutive years . . . . $= 0 \cdot 77$ to $0 \cdot 79 \times R_m$.

Thus, if Q = daily quantity in gallons, for all purposes, required to be supplied from the reservoir, then

$$Q = 62 \cdot 15 \text{ A} \left(\frac{4}{5} R_m - E\right).$$

Which gives the relation between the area of gathering-ground and the quantity it will supply.

But it is further desirable to know the size of reservoir which will be required to equalize the rainfall over the three years selected. For this it is impossible to give any precise rule, it being so entirely a question of experience. But Mr. Symons has again furnished a statement which will be some guide.

The necessary storage will vary in different districts, for this reason, that in wet districts, the extremes both of wetness and dryness are less pronounced than in drier districts. Hence in a rainy country, a smaller reservoir will suffice than in a dry one.

The general judgment of experienced practitioners appears to be, that for large rainfalls, a storage of 150 days' supply, or even less, will suffice; but in drier districts it may be necessary to go as high as 200 days. And this is a provision which may reasonably be borne.

*Compensation.*—But there is another point that the engineer has to consider in laying out water-supplies from a gathering ground.

The essence of the arrangement is, that he takes possession of a stream; intercepts it from its former course, and turns its water away in a different direction for the supply of a town. But there will be persons residing, or having property, on that stream, who will have something to say about this arrangement; and engineers accustomed to such things know pretty well that riparian proprietors in this position have the habit of making themselves pretty loudly heard. They demand what is called water-compensation; and a few words will explain what this means.

Before the reservoir is made, the stream in question will vary exceedingly in its volume at different periods. In dry weather there will be very little water in it: while in heavy rains it will

be a torrent swollen to a flood. This variable state of things is very inconvenient for everybody on the stream.

Now when a reservoir is put in, it gives the opportunity of remedying, in a large measure, these evils; for it will act as an equalizer for the stream, just as it acts as an equalizer for the town-supply. When the floods come down they are absorbed in the reservoir, and in return for this, the reservoir, in addition to the supply furnished to the town, may be made to give out also an equalized supply to the stream in dry seasons. This is called compensation-water.

The quantity of compensation-water to be given may vary according to special circumstances; but in the manufacturing districts, it is usual to allow one-third of the total supply impounded; leaving the other two-thirds for the supply of the town. The quantity Q in the formula must of course comprehend both supplies.

It is usual to insert in Acts of Parliament stringent conditions to compel this supply of the compensation-water, and explicit provisions for determining its quantity. The most usual mode of gauging is by the flow over a weir, or through a measured orifice under a given head. But as these depend on calculation, the riparian owners have in some cases demanded a more positive determination; and Mr. Bateman has contrived an ingenious machine for this purpose, which actually measures the water, as a publican would measure a pint of beer. It will be found described in Mr. Bateman's magnificent work[1] on the Manchester Water-supply, p. 178 and illustrative figure.

A gauge-basin is prepared of exact known dimensions, into which the compensation-stream can be turned at any time; and the machine consists of a tumbling apparatus by means of which the stream can be turned into the gauge-basin instantaneously, and can also be diverted from it with equal celerity. By this means the duration of the flow into the basin can be exactly known, and the quantity flowing in a given time can be exactly determined.

*Quality of Water from Gathering Grounds.*—It is only necessary to say a word or two on this point.

If the grounds lie high, in hilly country, as they mostly do, the water is usually very pure and soft, not having much opportunity of acquiring contamination. If the lands are flatter and

[1] "History and Description of the Manchester Waterworks." By J. F. Latrobe Bateman, F.R.S., &c. London: Spon, 1884.

lower, the water flowing over them will have more chance of taking up foreign matters, and in these cases filtration is sometimes necessary.

There is, however, one kind of effect to which water, even from the highest land, is liable, namely, to discoloration by peat. Most of these high lands contain, in certain spots, masses of decaying vegetation, in the shape of morasses or peat-bogs. These collect the rain-water like sponges, and when it flows away from them, it carries with it small particles of the vegetable matter, which render it brown in colour. This is no great detriment to the use of the water; the presence of these brown particles does not render it at all unwholesome; but still it is objectionable to look at.

It is said, and I believe with truth, that this water will bleach if allowed a long run in an open conduit exposed to the light and the air.

And I may here notice an ingenious arrangement contrived by Mr. Bateman for diminishing the collection of brown water in districts where much peat exists. It is well known that the colour is worse in the time of floods, when the greater flow of water through the peat-bogs washes the vegetable particles out of them. Mr. Bateman has cleverly taken advantage of this fact to effect his object, by a "separating weir" as shown in his before-mentioned work on the Manchester Waterworks (p. 128 and illustrative figure). It consists simply of forming across the stream channel a narrow slit which communicates below with the clear-water reservoir, or a passage leading to it. When the stream is clear, it moves slowly, and falls through this slit; but when it is in flood, moving with a higher velocity, it is carried over the slit, without falling into it, and flows away by the natural course of the river.

*Examples.*—Towns supplied from gathering-grounds are very common in hilly districts. I need not give any list, or any elaborate descriptions, but I will just name three of the most celebrated cases.

One is the supply of Glasgow from Loch Katrine, which was carried out by Mr. Bateman in 1859. The loch, lying 367 feet above the sea, forms a large reservoir for the catchment-basin above it, in which the rainfall is very large—70 to 90 inches per annum. To fit the lake for supply purposes, its level was raised 4 feet, and arrangements were made so that it could be drawn down 7 feet in all, thus giving an available storage of 5,600 millions of gallons.

The conduit from the lake to Glasgow is 26 miles in length,

of which 13 miles are in tunnel under hills, and 4 miles are in iron pipes across valleys. It will deliver about 50 million gallons per diem.

The cost of the works was about £1,000,000 sterling.

The two other large supplies I will mention have rather a curious history. About the year 1869, there was a good deal of discussion as to the water-supply of London. An impression was prevalent that the Thames ought to be abandoned; and two projects were proposed for supplying the metropolis from distant sources. One was by Mr. Bateman, from the head-waters of the Severn in North Wales; the other by Mr. Hassard from the lake district of Cumberland.

In both these places the rainfall was large, and the water of unimpeachable quality, and the designs were both excellent and perfectly practicable. They were referred to the Duke of Richmond's Commission, who, however, came to the conclusion that, for the present at least, the metropolis did not require them; and they ventured a prediction that the fine sources of supply in these districts would probably be found more useful for the large towns lying nearer to them in the north-west of England.

This has actually occurred. Manchester has taken possession of the Cumberland, and Liverpool of the Welsh supply.

The supply of Manchester and its outlying dependencies, from Longdendale, laid out by Mr. Bateman in 1847, has proved insufficient for the growing demand, and in 1879 an Act was obtained for taking water from Thirlmere lake, close to Hellvellyn.

The lake is but a small one, and to fit it for storage, its level will be raised 50 feet, which will give an available capacity of 1,300 millions of gallons. The rainfall is high—some 75 inches per annum—which at present is all wasted in useless and mischievous floods, and it is estimated that a supply of 50 million gallons per day may be obtained.

The natural outlet of the lake is to the north; but by boring under Kirkstone Pass, a discharge will be effected at the south end, and this will be brought to Manchester by a conduit 100 miles long. It will also supply, if necessary, towns along the line.

The lake is 533 feet above the sea, and the height gives ample fall.

The estimated cost of the work is £3,500,000.

Liverpool has been supplied for many years partly by old wells in the sandstone, but chiefly from gathering-grounds at Rivington, laid out by Mr. Hawksley many years ago. But here also the

demand outgrew the supply, and larger sources had to be resorted to. The gathering-grounds of North Wales were fixed on, and the works of supply are now in progress.

The River Vyrnwy, one of the head-waters of the Severn, is embanked in a favourable spot, forming a great artificial lake of 1,100 acres area.

The height is about 825 feet above the sea, and the water will flow to Liverpool by a conduit 67 miles long, including 4 miles of tunnel.

The quantity to be obtained is estimated at 40 million gallons per diem.

### Rivers.

The third mode of making rainfall available is by drawing it from a river, of some magnitude, flowing through low ground. It is a very common thing to find large towns situated on or near large rivers. Probably one of the motives for establishing them there may have been to furnish them with a convenient water-supply; but at any rate, when a river of fresh water flows close to a town, it offers, *primâ facie*, the most obvious source for this purpose, and many towns are so supplied.

We may say something as to river supplies, both as to quantity and quality.

In the first place, as to quantity. The capability of rivers in this respect was investigated at some length by the Royal Commission of 1869, having reference specially to the Thames.[1] They pointed out that the river was fed, not so much by the drainage of rain from the surface, as by the delivery of water through springs from the large stores laid up in permeable strata; and that this fact gave a permanence of flow which was of great importance in water-supply. As a proof of this, it was remarked that during long droughts, when many towns depending on catchment-supplies were in great distress for water, the Thames and the Lee seemed not to have been diminished below the ordinary flow of dry years, a result entirely due to the equalizing effect of the great subterranean stores contributing to them. The Royal Commission reported "That the abundance, permanence, and regularity of supply, so important to a large town, are secured much more efficiently by the great extent and varied geological character of a large hydrographical basin, than by the very much more

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[1] Report, pars. 82 to 94; and 259.

limited collecting areas available on the catchment system." And this remark will apply to river supplies generally.

In regard to quality, however, there is much more to be said, as it is on this ground that objections are usually raised to river supplies. We may exclude from consideration those rivers which are specially fouled by manufacturing operations, as in Lancashire and Yorkshire, confining our attention to rivers which flow chiefly through open country and agricultural lands.

Referring back to my remarks on quality generally, I mentioned three classes of impurities; and these have all to be considered in regard to rivers.

First, there is the class of impurities held in mechanical suspension. All rivers of any magnitude are liable to be more or less turbid, by the surface drainage of lands; but, as I have explained, such impurity can always be removed by efficient subsidence and filtration.

Secondly, as to mineral matters in solution. A river will almost always contain lime, from its being largely fed by springs; but this is so modified by the surface drainage, that the hardness is usually very moderate; and in this particular, therefore, no great objection generally arises.

It is the third class of impurity, namely, organic contamination, which is of the most importance. And I have purposely postponed the consideration of this till now, because it is in river supplies that this kind of contamination is most to be feared.

I repeat that this, like all other points regarding quality, is a matter specially for chemists, and that the best professional advice must always be called in before a final judgment is arrived at as to the propriety of using a river-supply. But I also repeat that a water-engineer is bound to have a certain general knowledge of the subject; and taking well-ascertained data as his guide, he is expected to form, by careful observation and common-sense reasoning, at least some preliminary judgment on the case before him. All therefore I profess to do is to specify a few points that may reasonably occupy the engineer's attention in regard to the organic contamination of river-water.

In the first place, we must not be frightened at the name. There is often a horror of the very idea of "organic contamination" in drinking water. But this, taken generally, is a mere foolish prejudice. We must recollect that all our solid food is organic, and almost all our drink, except water, depends on organic matters for its pleasantness and its usefulness. Hence the mere fact of

water containing organic matter means nothing against it. We must discriminate what kind of matter it is, and where it comes from.

Water washing over land surfaces, covered with vegetation, must necessarily collect organic particles. But these will for the most part be harmless, and when filtered the water will be perfectly wholesome. Even decaying vegetable matter, though it may be offensive, is seldom noxious. There is a very common example of this in peaty water, which really comes from decaying vegetation, but which no one objects to, except for its colour.

The contamination to be guarded against is that of animal origin. River water is liable to be polluted with the excreta of animals, sometimes in the worst form of concentrated town sewage. No doubt this kind of contamination is both disgusting and dangerous; and it would offer a most powerful objection to the use of rivers as sources of water-supply, were it not for a great principle of nature that tends strongly to counteract its evils.

This principle has been fully explained by the chemists. The noxious substances forming animal excreta are, generally speaking, exceedingly instable in their chemical composition; and in the presence of oxygen they are constantly tending to change, this change involving a destruction of their noxious properties, and their conversion into inert, harmless compounds. This change or oxidation will, we are told, be certainly brought about by exposure to the air, or to the action of water, which almost always contains free oxygen enough to produce the effect required.

Nobody, I believe, disputes the existence of this purifying influence; indeed, if it did not work daily, the civilized world could not go on. The only points of disagreement are as to the extent of its action, and the time necessary to effect it in certain cases.

Now, keeping this principle in view, let us consider what are the circumstances that give rise to the organic contamination of rivers.

It is not uncommon to hear it said that a river must be necessarily contaminated with the excreta of the whole of the inhabitants living on its area of drainage. But such a statement is a gross exaggeration, and ignores the purification principle altogether. What is the position of the inhabitants on the drainage area? The fact is that a very large proportion of them live in what may be called the country, *i.e.*, widely and sparsely dispersed over the land, and not collected in towns. In the basin of the Thames, for example, above the tideway, less than one-fourth live

in towns of two thousand inhabitants and upwards, three-fourths being spread over the wide surface of the country.

Now everybody who has seen life in these country districts must know that the excreta both of the human and of the lower animals are, as a matter of ordinary economy, disposed of directly upon the land, and it is notorious that such a disposal is the most favourable for their complete oxidation, and for the speedy destruction of their noxious properties.

It is generally admitted that by the application of animal excreta to land, in the manner known as "sewage irrigation," if laid out and managed to the best advantage, the noxious elements will become oxidized and destroyed. It follows, therefore, that, so far as regards all these country-produced excreta, the whole drainage-area forms one immense sewage-farm, on a scale of efficiency sufficient to purify hundreds of times the quantity thus put upon it. Hence, so far as this element of pollution is concerned, no great fear need be entertained as to any dangerous contamination of the river water.

Again, we often hear about the pollution by the washings from manured lands; and even the sheep, cattle, and birds are accused of poisoning the river water. But here again the same principle applies; the excretal matters being exposed to oxidation and destruction in the most favourable way.

That this reasoning is true is proved by the most ordinary common-sense considerations. These causes of organic contamination have been at work for ages; ever since the lands have been inhabited and cultivated. And during the whole of this time the rivers have been used as sources of water-supply to the whole country, and nobody has been poisoned; in fact we may say, in regard to the bugbear of universal organic pollution, in the words of one of our most entertaining poets—

> "In spite of all this terrible curse,
> No one has seemed a penny the worse!"

We must not, however, forget that we have the other fraction of the population to consider, namely, those who are collected in towns lying on the river or its tributaries above our proposed source of supply. For if these towns are systematically drained, and discharge their sewage into the stream, there is undoubtedly introduced thereby an element of contamination of a really serious character.

This cause of pollution is, it must be observed, of comparatively recent introduction. It has brought in elements of offensiveness,

and indeed of danger, which have not existed before. While the river was left to natural pollution only, it worked its own natural purification. But now that we take pains artificially and purposely to damage its quality, it is by no means certain that the same result will follow.

But even in this worst of all contaminations, the case is not hopeless. In 1876 an Act was passed to prevent the pollution of rivers; and it provided that no sewage shall be allowed to flow into any stream until the authorities of the place have used the best practicable and available means of rendering it harmless.

This opens the very large question of sewage treatment, which I cannot pretend to discuss here. I will only allude to the two modes now generally practised. The best is what I have already mentioned, namely, application to land—by sewage irrigation or filtration. If this process is fully, efficiently, and carefully carried out, all authorities agree that the noxious qualities are practically destroyed, and the water is restored to a state closely approaching its original harmlessness. The other process is by chemical precipitation. By this the worst parts, the suspended solids, are removed, and so a great deal of good is done; but the effluent will still be impure.

However, we must not leave out of sight the great saving element of the purifying power of the stream. For if, after either of these processes, sewage-contamination is still introduced, yet provided a sufficiently long run, and a sufficient time, are given, nature will probably do what is necessary to complete the purification.

Several processes will assist in this work. In the first place, a portion of the organic matter will be removed by fish and other animal life. A further portion will be absorbed by the growth of aquatic vegetation. Then we have, finally, the decomposing power of the fresh water in the river, which always contains much free oxygen, eager to attack the instable organic compounds the moment they enter. And this action is very much facilitated by the motion of the stream, particularly if it falls over weirs.

Chemists differ as to the extent and as to the speed of this purifying action, but, as a matter of practical observation, its beneficial effect is most positive and unquestionable. In many cases where a mass of sewage has been bodily discharged, in its most crude state, into a running stream, no trace whatever has been found of any deleterious matter, either by chemical tests or by practical use of the water, a few miles lower down.

I say this, however, with a reservation as to what is called the

"germ" theory. Some authorities have expressed the opinion that if the germs of certain zymotic diseases once enter town-sewage, they cannot, by any practicable treatment, be destroyed or removed, and that water receiving such sewage should always be considered as dangerous, and improper to be used for drinking. On the other hand there are many authorities who think this theory merely fanciful, and unsupported by evidence. It is beyond my province to discuss the point. I only mention it, and it must have the consideration it deserves.

On the whole, however, I believe it to be a sound conclusion that, although every care and caution should be used in adopting river supplies (which are often so very convenient), they ought not, by unreasoning prejudice, to be tabooed as ineligible. It is the business of the engineer to make the great powers of nature subservient to our use and convenience; and the purifying power of nature is certainly one that he should take advantage of if he can.

It is worthy of remark that in some cases the water of a river may be taken, not out of the river itself, but out of the thoroughly saturated bed in which it runs. It often happens that the ground through which the river forms its course is gravel, or some open porous alluvial stratum. This is of necessity charged with water, and a plentiful supply may be drawn from it, which has undergone a natural filtration. The supply of Oxford is obtained chiefly in this way, and the same thing has been lately done to a considerable extent by some of the London water companies, who find a fine, clear, and ample supply in the gravel beds near the Thames at Hampton. The water in these cases does not necessarily come from the river; it may often consist of springs and subterranean drainage waters, which are flowing towards the river, and are intercepted on their way.[1]

Supposing a river to be chosen as the source of a town-supply, the operations of taking it are so simple as not to require any detailed description. The water is first allowed to deposit its grosser particles by subsidence in large tanks, after which it is filtered, in the manner I have already described, and is then pumped up to the town.

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[1] Mr. John Thornhill Harrison, one of the Engineers of the Local Government Board, has lately published some important and valuable Reports (3 July and 4 August, 1884) on the subterranean waters contributing to the Thames, with proposals founded thereon for the improvement of the water-supply of the metropolis.

## Wells.

The modes of utilizing the rainfall which we have hitherto considered, have all been founded on the supposition that we take the water on the surface of the ground. But some portion of the rain will percolate through pores and fissures of the earth, and will store itself subterraneously in permeable, or as they are termed water-bearing strata. In some districts where these strata form the surface beds, the rain disappears with marvellous rapidity, and in these districts consequently there are few or no surface streams. On the chalk downs, for example, there are no rivulets in the valleys; the water that would feed them has all gone below.

The water is stored in these strata in two ways. First, in the pores of the rock itself; and when the material is of an open grain, the quantity of water held in it is much more than one would suppose. But this storage is largely augmented by cracks, fissures, and hollows. These are very important, for they serve not only as reservoirs, but as drains to the substance of the rock generally. And it is by tapping these fissures that the most plentiful supplies are obtained.

The most common mode of making use of subterranean waters is by the old plan of sinking wells.

There is a marked distinction to be drawn between shallow wells formed in superficial ground, and deep wells sunk into the lower subterranean strata. Shallow wells are exceedingly common and exceedingly useful. The alluvial beds lying so largely on the surface of the earth receive water very readily, and wells sunk therein form the chief sources of supply in country places generally.

Now although the water of surface wells is often not very good, yet, if the strata are not liable to be specially contaminated with noxious refuse, it may be safely used. But this condition is not always present. Even in an isolated farm-house or country residence there must be a cesspool or similar receptacle, and there is danger, unless great precautions are taken, of liquid from this penetrating the strata, and getting to the well.

In towns this kind of contamination is much more probable, and surface wells become consequently especially dangerous; so much so as to be generally prohibited for drinking purposes by health authorities. The alarming outbreak of cholera in Soho some years ago, due to a contaminated surface well in Dean Street, will long be remembered.

But deep wells, drawing their supplies from strata lying low in the earth, are in a different category, and form excellent sources of water-supply.

In some cases a deep borehole will tap a water-bearing stratum covered by impervious beds; and the water, being fed from higher levels, will rise up the borehole, sometimes above the surface of the earth. This is the phenomenon called an Artesian well, with which all will be familiar. But wells of this kind are exceptional. The ordinary well is a large shaft sunk into a water-bearing stratum, where the water lies at a low level, and has to be pumped up to the surface.

The two most important water-bearing strata in England are the chalk and the new red sandstone; and many towns are supplied from them.

We may consider a little what takes place in regard to the water in subterranean strata. It is not stationary, it tends to move away towards low points, where it can find an exit in springs, or into low-lying rivers, or into the sea. And as a consequence of this motion it is found that the line of water-level within the strata is always slightly inclined towards the points of discharge, the angle of inclination representing the head necessary to force the water through the interstices of the rock. In the Proceedings of this Institution, vol. ix., p. 154, will be found an instructive section of the chalk strata near London, showing the water-line, inclined, as I have described, towards the Thames and the Colne. The inclination of the water-line varies, in this place, from about 13 to 26 feet per mile, according to the closer or looser texture of the material, but in many other places it is more rapid, sometimes reaching 40 or 50 feet per mile. The levels of the water in these cases are known by careful observations in wells sunk into the strata at various points.

It is instructive to note the effect that will be produced when we begin to pump out of a well. Before the pumping begins the water will stand at its normal level; but when the pumps are set to work, the surface of the water in the well will immediately descend. The reason of this is that, to supply the well, the water must flow into it from the neighbouring parts of the strata; and to enable it to do this, its surface must have an inclination to give it the necessary head to overcome the friction through the interstices. This produces a conical depression all round, the depth and extent of which will adjust itself according to the quantity of water pumped, so that, when this adjusted level is attained, the pumping may go on at the same rate without further

depressing the water-level. But if the rate of pumping is increased, the water will be further depressed, till it finds its proper level as before, at which it will remain. There will thus be found a stationary level of water in the well corresponding to every given rate of pumping, so long as this does not exceed the possible yield.

At the same time as the water-level in the well becomes more and more lowered, the area of the cone of depression extends farther and farther around, until it may reach a considerable distance; and this is the reason why a certain rate of pumping from one well may lower the level of water in another well in the neighbourhood; which simply means that the cone of depression belonging to the first well has extended so far as to reach the second well. Cases of this kind are very common, and sometimes give rise to a good deal of trouble.

In order to increase the facility of getting the water out of the strata, it is customary to drive tunnels from the well in various directions, so as to enlarge the area of collection. A good example of this is found in the Brighton Waterworks, of which an account has been given by Mr. Edward Easton in the Transactions of the Brighton Health Congress, 1881, p. 48.

Brighton is surrounded on three sides by chalk strata, which absorb a very large quantity of water. The level of the water can be easily traced by wells, and it is found to rise gradually from the sea at the rate of about 40 feet per mile; this slope representing the friction of the current flowing down gradually into the sea, as it is replenished by fresh stores, either from the rain above or the chalk strata behind. Two wells were sunk to the depth necessary to reach the water-level; but these alone did not furnish sufficient water, and tunnels or adits were driven to increase it. It was found that the chalk was largely fissured; the fissures mostly extending longitudinally from north to south, indicative probably of the erosion of the rock by the subterranean flow of water in that direction. Advantage was then taken of this fact by driving the tunnels from east to west, so tapping the fissures successively at right angles, and the result was a very copious supply. The quantity pumped is about 3½ millions of gallons per diem.

In regard to the quantity of water which may be got out of a well, no rule can be given. Some people have fancied that (as I have said in regard to lakes) these subterranean reservoirs contain an unlimited store, and may be pumped from *ad libitum.* I need hardly say here that this is a delusion; the only source of supply is rain, which gets into these strata from their exposed surfaces, and the yield of a well must always depend, first on the amount of

rain which the strata can collect, and secondly, on what portion of this can be enticed into the borehole. Neither of these can be determined beforehand; and, therefore, the quantity to be got must be a matter of experience.

The water obtained from wells is usually bright and clear, and free from organic matter. This is the result of the natural filtration it has undergone. But it is generally rather hard, and is well adapted to treatment by the softening processes I have described in a former part of my lecture.

### Springs.

Finally, as a mode of obtaining water we may make use of springs.

The nature of a spring is familiar enough to those who have studied geology. It is simply a place where the water stored in a subterranean stratum finds access to the surface of the ground, at such a low level that the head of water lying above it keeps up the discharge.

There is not much to say about supplies obtained in this way. The springs are simply collected and conveyed to reservoirs for distribution. One of the most magnificent examples was the New River, a conduit 40 miles long, constructed by Hugh Myddelton in 1613, to bring into London the clear waters of springs at Chadwell and Amwell in Hertfordshire.

Lancaster is supplied by springs in the high moorlands of Wyresdale, 8 or 10 miles from the town, the waters being intercepted by small pipes, and brought down by large mains. The works for this purpose were originally designed in 1852 by Sir Robert Rawlinson, and have since been extended by Mr. Mansergh.

Malvern is also a good example. A great many springs were found to be issuing from the sides of the well-known hills in the neighbourhood, and have been utilized by Mr. Hawksley, so as to afford an ample supply of water of the purest kind.

In regard to the quantity obtainable from springs, engineers ought to be very cautious, for there is no means of determining *à priori* how their flow may vary; and in dry seasons they may fail altogether.

### Internal Distribution.

Having now gone over the several modes of obtaining water for town supplies, I pass on to a branch of the subject which applies

to all these modes alike, namely, the distribution of the water within the town.

The first step in this usually is to bring the water to reservoirs constructed near the town, at such elevations as shall allow it to flow by its own gravity throughout the district. These reservoirs are called "service"-reservoirs.

If the water is obtained from a gathering-ground, the source will usually lie at such an elevation that the water may flow down along a conduit from the catchment-reservoir into the service reservoirs. But if the supply is obtained from a low-lying river, or from wells, it must be forced up to the service-reservoirs by pumping power. Such is the case in London, where steam power to the amount of 17,200 HP. is in use.

I might here go into the subject of pumping-engines and pumping-machinery, but this is hardly necessary, as the subject has often been discussed before the Institution. I will only make two remarks of a very general character.

In the first place, in pumping through a long and large main, it is most desirable to keep the current uniform and regular, avoiding shocks or sudden changes of velocity, which are very trying to the metal, and often cause bursts. For this reason it appears to me that double-acting engines, regulated by a fly-wheel, are to be preferred to single-acting ones of the Cornish type. The Cornish engine had, many years ago, a justly earned reputation for superior economy; but now that the use of steam is better understood, this no longer exists, and I cannot see any other motive for the retention of this form of engine.[1]

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[1] The history of the application of the Cornish form of engine to waterworks purposes is curious. Some half century ago the engineers of the centre and north of England became aware of the reports published from time to time of the extraordinary economy of the pumping engines in the mines of Cornwall. These reports at first obtained no credence, and even when they were found to have some foundation, the most singular attempts were made to explain them away. In the midst of this controversy Mr. Thomas Wicksteed, the Engineer to the East London Water Works Company, determined to throw light on the question by buying an engine in Cornwall and setting it up to work on his own premises, where it could be thoroughly tested and examined. The result was fully to establish the truth of the great economy claimed, and so arose the idea of the superiority of the Cornish form of engine for pumping purposes.

When, however, the working of the engine came to be investigated, it was found that the economy was due chiefly to the large amount of expansion made use of, combined with some other modes of economising heat; and there appeared no reason why, by proper measures, these might not be as efficiently carried out in other forms of engine. Accordingly when the new Lambeth Water Works were designed, in 1848, Mr. James Simpson, the engineer, commissioned Mr.

The same principle of regularity of motion also dictates a preference for a particular form of double-acting pump, called the "bucket- and plunger-" pump. It is simply a lifting bucket-pump, the rod of which, passing through a stuffing box at the top, is enlarged to one-half the area of the pump-barrel. The effect of this is that in the down-stroke the rod acts as a plunger, and expels an equal quantity of water to that effectively lifted in the up-stroke. I do not know who invented this ingenious contrivance, but it was made for the Lambeth Waterworks pumping engines by Messrs. Simpson and Co. in 1848. Its advantage is that, although the pump is double-acting, the motion of the water through it is always in the same direction; whereas in the ordinary double-acting pump it is reversed in the barrel at each stroke. Owing to this peculiarity of the bucket- and plunger-pump, it is possible that the motion of the water may continue to some extent at the dead points, and under certain circumstances I believe that the curious result has occurred of the pump delivering more than its calculated quantity.

There is another point in regard to pumping-machinery worth mentioning, that is, the necessity of duplication. Everybody knows that, in spite of the utmost care in the manufacture, accidents will happen, and hence a duplicate provision of engine and pumps is an absolute necessity where the supply of a town is at stake. Such a provision is also highly expedient and economical in order to give proper intervals of rest for cleaning and repairs.

It sometimes happens that a town lies in such flat ground that no elevated site for service-reservoirs can be found. In this case a tower may be built, and a reservoir placed on the summit, forming what the French call a "château d'eau." Such erections are, however, expensive, and in some cases the plan is adopted of pumping directly into the distributing mains, so giving the necessary pressure by steam power, and not by the gravitating head from a high-service reservoir.

This, however, is both a difficult and a disadvantageous plan. It is difficult because of the constantly varying consumption, which renders it troublesome to regulate the working of the engines, so

David Thomson and myself to endeavour to design engines in which this should be done. The result was the construction of some large engines on the compound or double-cylinder principle, which fully realised the expectations entertained of them. Since that time the compound principle has been further developed, and the superiority of the Cornish form exists no longer.—See Wicksteed on the Cornish Engine; Pole on the Cornish Engine; and a Paper in the Transactions of the Institution of Mechanical Engineers, July, 1862.

as to adjust the quantity pumped to the draught on the mains. It is, moreover, disadvantageous to supply a town by direct pumping, because this plan is unfitted to give a large and free supply on a sudden emergency in case of fire. High reservoirs will do this naturally, being always ready if kept properly filled, as careful waterworks authorities will take care they always are, particularly in the night, when fires are most likely to occur. It is obvious also that they provide for fluctuation in the town consumption, while they allow the engines which supply them to work at uniform speed and uniform pressure, the most advantageous conditions in every way.

Sometimes, when there is a small high-service reservoir, the two plans are combined. The engines pump into the town at the same time as they pump into the reservoir, which then acts as a regulator, equalizing both pressure and quantity.

The size of the service-reservoir must be sufficient to fit it for the double duty before named, *i.e.*, to regulate the fluctuation of the demand, and to hold a store for sudden emergencies. It is found that these objects will be attained if the reservoir holds from one to one and a half day's supply.

Service-reservoirs, if they are in or near the towns (as they usually are), ought to be covered. This has several advantages. It preserves the water from contamination by soot and dirt falling from the air. It keeps the water cool in summer, and will go far to prevent it freezing in winter; and by excluding the light it is said to discourage the growth of vegetation, to which some waters are very liable. The London Water Acts require that all reservoirs of filtered water within five miles of St. Paul's shall be covered.

When a town is very hilly, it is necessary to have several service-reservoirs at different levels, in order to avoid too much pressure in the distributing mains at the lower parts of the town. For this purpose the town is divided into zones of different levels, each having its own service-reservoir.

From the service-reservoirs the water is made to flow by cast-iron pipes (or "mains," as they are termed), which ramify in all directions through the streets, the sizes being of course properly proportioned to the maximum quantities of water flowing through them. From these mains the water is carried by communication-pipes (usually of lead) into the houses. I need not go into any description of this system of pipes, with all their various connections, valves, and appliances; they will be familiar enough to you.

*Constant and Intermittent Supplies.*—I must, however, say some-

thing of the two systems under which town supplies are given, namely, the intermittent and the constant service system.

The most natural and obvious way of supplying water is to keep all the supply-pipes constantly charged under pressure, so that whenever any customer wants water he has only to open a cock or tap to get it. And no doubt this must have been the mode attempted when house-supplies were first given. But a difficulty would soon arise. The cocks and fittings in the houses, after being in use some time, would begin to leak, and there would be a waste of water, which, if it became large, would overtax the powers of the waterworks to supply. This evil was so serious, and so very difficult to remedy, that it led to the introduction of an ingenious device to evade it. The waterworks people said to the consumer, "We cannot afford to give you a constant supply of water which you allow to run to waste. You shall put up a cistern in your house capable of holding as much water as you can reasonably use in twenty-four hours. We will fill that cistern for you at a certain time every day, and leave it in your care; and then if you choose to waste the water it will be your loss and not ours." This was done in a great many towns. The town was divided off into districts, each supplied from the chief mains by a special service-main, shut off by a valve. This valve was opened by a "turn-cock" for an hour or two every day, when all the house cisterns in that district were filled. Thus originated what is termed the "intermittent" system of supply. It was a great convenience to the companies, as it not only saved them from the waste, but (if the town was supplied by pumping) it enabled them to regulate the action of their engines with much facility.

But then arose sanitary difficulties. It was found that the storage of water in these house cisterns, which were generally very badly looked after, rendered it liable to contamination, particularly on account of connections with water-closets and drains. Hence when, some thirty or forty years ago, a great sanitary movement took place, the state of the water-supply of towns served on the intermittent plan was strongly condemned; and it was demanded by sanitarians that the house storage should be abolished, and the water served direct from the mains. It was proved that this could be done, and that the objection as to waste could be got over. I believe that our veteran Past-President, Mr. Hawksley, was the first, or one of the first, to show this. He laid out the supply of Nottingham in 1831, and it has never had any other than a constant supply—so con-

stant that the water has never been shut off since, except for a few hours at a time. Many other towns were afterwards similarly supplied by him. Mr. Bateman also successfully introduced the system at an early period, and warmly advocated it.

It being thus proved that the constant service was practicable, the Legislature, when they passed the Waterworks Clauses Act in 1847, enacted that, as a general rule, "the supply should be constantly laid on at such a pressure as would make the water reach the top storey of the highest houses."

Although, however, the difficulties have been surmounted, yet they have required a great deal of thought, attention, and ingenuity to make the system a success. This is most especially shown when it is attempted to change a town or district from intermittent to constant supply. In such a case it would not do simply to turn on the water for the whole day. The waste would be so enormous that no ordinary waterworks could meet it—it would simply be turning the water into the sewers. The promoters, therefore, have had to investigate, with the greatest care and perseverance, how this waste arises; to study every cause by which water can run away unutilized; and to meet every such case by attention to the most minute detail. The work of doing this has been much more difficult than is usually supposed, and its successful accomplishment has been a great triumph of mechanical skill. I will endeavour to give, as briefly and generally as I can, some idea of the nature of the defects, and the manner in which they are remedied.

In the first place, the introducers of constant service have convinced themselves that the evil does not arise to any great extent from a wilful, or even a careless, waste of water by the consumers. If it did, constant supply would be impracticable. No doubt such waste does occur to some extent, but it may easily be kept down by stringent prohibitions and moderate inspection. It is found that among all classes of the public there prevails a sufficient sense of propriety to prevent serious waste, which is generally a nuisance and an inconvenience to the consumer.

The principal difficulty in this respect has been the mistaken zeal of sanitarians, who have told the poorer classes that it is a good thing to let water run to waste in order to clear out the drains. This is a gross blunder. It has been pointed out over and over again that these little dribblings can have no effect whatever in removing any obstructions or accumulations. The ordinary domestic use of water is quite sufficient, if properly managed, to keep house-drains clear, and as to large sewers, it is the business of the

municipal authorities to look after them. The waste of water in a house can do no good, and may do much harm.

The waste to be fought against is due, not to the action of the consumers, but simply to defective arrangements in the pipes and fittings. It may arise either in the streets or in the houses; and occurs frequently in both. Let us first consider the house-fittings.

In the first place the pipes may be too weak. With constant service the pressure is high and continuous, and the pipes may give way. Hence a scale of strengths of pipe must be prescribed.

Then the joints of the pipes are often badly made and leak. This also must be provided against.

Then the draw-tap is of much importance. The ordinary plug-tap is a very bad thing: it has two defects. First, it shuts the water off too suddenly, causing a jerk and great strain; and secondly, it soon gets leaky; and the constant dripping from a leaky tap will run away with an enormous quantity of water. The use of this kind of tap is forbidden, and a screw-down tap is always provided; it shuts the water off gently, and if of proper construction will keep in order a long time, and may be repaired with great ease.[1]

The ball-tap, which is necessary to some extent even under constant service, is the source of much waste. There are two precautions against this: first, to get the article of thoroughly good construction; and secondly, to ensure its being promptly attended to when out of order. This last object is provided for in a particular way. It is forbidden that any cistern shall have a waste-pipe by which the water can run away into the drains unseen. The only overflow must be by a pipe which discharges into some conspicuous place, where the discharge will attract attention, and produce inconvenience. This is called a warning-pipe, and its action will compel a householder to get the tap repaired without delay.

Then one of the greatest causes of waste has been the supply to water-closets. The ordinary apparatus, if properly used, does not consume more than a fair quantity; but it is liable, in the first place, to get out of order, and secondly, to be grossly abused, by propping up the handle, under the mistaken notion already alluded to, that this is good for the drains. The remedy is an ingenious

[1] The screw-down tap was invented by Mr. Edward Chrimes of Rotherham, and was patented by him in March, 1845. Some years ago there was a long and hard-fought dispute before the magistrates of Edinburgh as to the construction of tap proper to be used in constant-service fittings, which resulted in the condemnation of the ordinary plug tap, and the establishment of the screw-down tap as the only suitable thing.

contrivance called a waste-preventer. It exists in several forms, but the one most generally approved is the divided cistern apparatus, which I believe was first designed by Mr. Hawksley. The cistern is divided into two parts, which I may call A and B. A is fed from the main by a ball-cock in the ordinary way; and when the apparatus is at rest there is a communication open between A and B, which fills B. When the handle of the apparatus is pulled, after using the water-closet, the water contained in B is let down into the pan, but at the same time the opening between A and B is closed, so that no more water can be used than B contains, and therefore no waste can be caused, either by accident or design. When the handle is let go, the communication between B and the pan is closed, and that between B and A opened, which charges B again for another use when required. When this is properly made it will keep in order a long time, and is very easily repaired; and it forms as efficient a flushing apparatus for the drains as can be devised.

This, or something equivalent to it, is the only apparatus that is allowable for a water-closet, under the constant-supply system. All simple cocks and valves are expressly forbidden, not only as allowing waste, but on sanitary grounds also. In the poorest class of houses, where the expense of the waste-preventer would preclude its use, it is better on every ground to allow the water-closet pan to be flushed down by hand, than to "lay on the water," as it is termed, by an imperfect and wasteful cock or valve.

There are other precautions in regard to baths, hot-water boilers, and so on; but I need not trouble you with further details. I have said enough to give you a general idea of the nature of the precautions used.

These precautions are always embodied in a set of Regulations, which are carefully prepared, and which the water authority of any town must have power to enforce strictly and stringently; otherwise the great boon of constant water-supply cannot be given.

But they must be supplemented by another power; that is, a control over the plumbers, who do the fitting work; for in spite of all provisions as to the construction of particular articles, if the work generally is badly done, it may give immense trouble. I am sorry to say that the character of the trade generally is not such as could be wished, and great trouble has been experienced on this head, from the difficulty of obtaining any legal control. But the water authorities have generally adopted the plan of keeping lists of "authorized plumbers," who enter into an engagement to con-

form to the regulations and to do their work in a proper and creditable manner; and the moral control thus given has been usually found effective.

Then finally the water-authority must have a reasonable power of inspection, and of inflicting penalties for wilful or careless waste. But, as I have said before, experience has not shown that this is, or need be, carried out in an oppressive or offensive way.

These measures have been found to suffice for checking the waste so far as the house-fittings are concerned. But there is another cause of waste more difficult to deal with; namely, from leakage in the mains and service-pipes in the streets. The mains often get disarranged by the traffic and leak at the joints; or the small pipes leading into the houses decay or get damaged; and leaks from these sources will often go on for a long time undiscovered, the water finding its way into the drains. This cause of waste is often most troublesome in changing from the intermittent to the constant supply.

The difficulty is to find such leaks, and their discovery has been much facilitated by an operation that was introduced in Liverpool some years ago, and which has been fully described to this Institution by Mr. Deacon.[1] It consists in isolating a certain district, and in ascertaining what quantity of water is used therein, at any given time, by applying, temporarily, a meter on its supply main. This will indicate whether more water is passing than ought to be consumed there, and then, by a detailed examination, the locality where the waste takes place can be soon identified. One means of doing this is ingenious; namely, by placing a "hydrophone," or sounding bar, against any suspected pipe, when by applying the ear to the other end of the bar, the passage of water through the pipe can be distinctly heard. This will not only detect street leakages, but may also give an idea whether waste to any serious extent is going on in the houses. The leak-detecting operation here described has been of great utility, and has done much to facilitate the introduction of constant supply.

The history of the London supply in regard to constant service is curious and instructive.

Until within the last ten years the supply was entirely on the intermittent plan. The usual sanitary questions had often been agitated; in many districts the supply was disgracefully bad; the propriety of introducing the constant service had been often suggested; and in the Water Act of 1852 a provision had been

[1] Minutes of Proceedings Inst, C.E., vol. xlii., p. 129.

made to that effect. But, notwithstanding the well-known fact that this system was successfully at work in other towns, the measure was always opposed by the companies, on the ground that the waste would be so enormous as to render the system impracticable. And in the face of this opposition, nothing was done.

Still, however, the demand for the change was very urgent. It was strongly recommended by a House of Commons Committee in 1867, and again by the Duke of Richmond's Royal Commission in 1869; and immediately after this last date the Government, earnestly desirous to carry out the measure, determined to institute inquiries as to its practicability.

They did me the honour to entrust me with the investigation; instructing me to visit several country towns where the system was said to be in effective operation, and to make myself thoroughly acquainted with the facts, and in particular with the modes of preventing the waste that was so much dreaded; and having done this, I was to examine the state of things in London, and report if there were any real obstacles to the application of the system there.

The reports which I made on this matter were published as Parliamentary Papers, and are well known to all parties interested in the question.

The general results were these:—In the first place I found that the system was in perfect and successful operation in many towns; that several towns had been and were being successfully changed from the intermittent to the constant system; and that under this system the consumption of water was much less than under the intermittent plan in London. I also described fully the causes of waste and the means adopted, with success, for checking it.

In the second place I described the result of my examination of the circumstances of the London supply, and I endeavoured to show that, if proper means were used (which I described in some detail), the constant service might be successfully brought into the metropolis. And I ventured to express the opinion that the change would be attended, in the end, rather with an economy than with a waste of water.

It was a great satisfaction to me to know that this Report not only satisfied the Government, but also to a large extent satisfied the Water Companies. For when, in the following year, a Bill was brought in for the purpose of effecting the change, the companies accepted it in a conciliatory spirit, and it became law on the 21st of August, 1871. Under the provisions of this Act a long inquiry was held in 1872, by Commissioners appointed by

the Board of Trade, for the purpose of settling the Regulations to be adopted for efficiently carrying out the constant-service system; and having paid so much attention to the subject, I took an important part in the discussions before the Commissioners. The result was the establishment of the code of Regulations now in force.

Soon after that time the change began. It was introduced very gradually, and required much caution; but at the present time nearly half the houses are so supplied.

In some districts I believe the change has effected a reduction in the consumption; but in other places this has not been so, a complaint being made of an increase in the waste. I do not know enough of the facts to give any positive opinion as to the causes of this; but I strongly suspect it may arise from a want of proper control over the plumbers and the fittings used; for I was obliged to point out that the character of the plumbing trade in London was, in my opinion, the greatest obstacle to the introduction of the new system. But I am confident that the difficulty may be got over, and I should hope, for the credit of our London water-engineers, that the time will not be far distant when the metropolis of England will be as well supplied as Nottingham and Norwich and Manchester have been supplied for the last quarter of a century.

It cannot be denied that the provisions for constant service involve a little more outlay, both to the suppliers and the consumers; but this is largely outweighed by the advantages to both parties. The suppliers have to go to somewhat greater expense in their service-reservoirs and in their mains, so as to provide efficiently for the fluctuations in the demand at different times in the day, as I have before explained. But they may reap an enormous advantage in the saving of waste, which will most unquestionably be effected, if the system is carried out vigorously and thoroughly. The experience of all towns where constant service has been effectually acted on is positive, that under this system the consumption may be reduced to the minimum possible, while under the intermittent plan it is always extravagant and wasteful.

Then the consumer has to incur a little more cost for fittings of more perfect character, and of better quality; but he gets amply repaid, not only in the greater purity and wholesomeness of his supply, but in the freedom from accident, and the less necessity for repair. For the very essence of the improved fittings is, their less liability to derangement and their greater durability.

I had intended to say something of the London Water Supply

more generally; but my time is gone, and I must be satisfied with referring you to the excellent reports of the energetic public inspector, Sir Francis Bolton. All I will say is that it has greatly improved of late years, and that so far as engineering points are concerned I do not think there is much to complain of. The agitations now are mostly about charges, which do not come within the engineer's province.

I have in conclusion only to express my acknowledgments to many friends who have kindly aided me with information for this lecture; among whom I may name Messrs. Hawksley, Mr. Bateman, Mr. Homersham, Mr. Ayris, Messrs. Simpson, Mr. Symons, and Messrs. Guest and Chrimes.

And, finally, I have to thank you all for the patience with which you have listened to what I fear must have been, in spite of the subject, a somewhat dry lecture.

Sir Frederick Bramwell, President, said he would ask the members to give a hearty vote of thanks to Dr. Pole for the lecture he had just delivered. He thought they were peculiarly fortunate in having his services for that purpose. There had been no important inquiry of late years, whether into the sources of water-supply or into the nature of fittings, in which Dr. Pole had not borne an important part. He was also, as was well known, the author of some most useful and intelligible formulas for the flow of water; and the members, he was sure, would agree with him in thinking that whether with regard to knowledge of the subject, or ability to bring it before them, it would have been impossible for them to have found any gentleman who would have better fulfilled the duty of lecturing upon the subject on which he had spoken.

Mr. Edward Woods rose with great pleasure, at the request of the President, to second the vote of thanks to Dr. Pole for his most interesting lecture. They would all fully recognise the ability with which he had dealt with so wide a subject, and would congratulate themselves on having been the hearers of his lecture.

The motion was unanimously agreed to.

Dr. Pole said he was exceedingly pleased at the way in which the members had condescended to receive his imperfect address.

5 March, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

# "Water-Motors."

By Professor W. C. Unwin, B. Sc., M. Inst. C.E.

When the Council did me the honour to ask me to lecture on Hydraulic Motors, I could not but feel that they imposed on me a task of some difficulty. The lectures of last year on the applications of steam power related to a matter of pre-eminent national importance, and to one involving some of the most striking and brilliant scientific discoveries of this century. In describing the work of Joule and Rankine and Siemens, the lecturers of last year were recalling names familiar and honoured in this Institution, and discoveries which form the most characteristic scientific advance of recent times.

Water-motors are not now, or in this country, so important as heat-motors, and there is even possibly, among many engineers, an impression that water-motors are at best rather feeble machines, suitable only for small industries. Nevertheless, I believe that even now a much larger amount of water-power is utilized than is generally known, and in circumstances not impossible, or even very improbable, the importance of water-power, even in this country, might be greatly increased. In some by no means very indefinitely deferred period, there must begin to be felt something of the pressure due to the limitation of the coal-supply. No great increase of the price of coal is needed to make water-power much more valuable than it is at present. On the other hand, if the electrical engineer will make the transmission of energy easier, the importance of water-power would also increase, for one of its greatest defects is that it exists in the localities where nature has placed it, and not in the places where it can be most conveniently used.

Numerous isolated cases of the transmission of energy electrically, to do mechanical work at a distance, are no doubt already in successful operation, but in most of these cases the installation has been more or less of an experiment, and the cost has not been

greatly regarded. But one case, in which the electrical transmission of water-power has been successfully carried out on a strictly commercial basis, has come under my notice. At Bienne, in Switzerland, the power of a Girard turbine is transmitted electrically a distance of 4,000 feet, and used to drive machinery in workshops. The dynamos are compound wound, and the conductors are carried on posts. A diminution in the cost of electrical apparatus would probably render such cases much more numerous.

The term water-power is convenient, but inaccurate. Strictly speaking, there is no such thing as water-power. Whether the water descends on a water-wheel, or actuates a pressure engine in connection with Mr. Ellington's hydraulic pressure-mains, the water is a mere agent of transmission. In the one case the water-wheel is driven by the energy of gravitation, in the other by the energy developed in a steam-engine; the water merely transmits the pull of gravity or the push of the steam-engine. In neither case is the water itself the source of the power utilized. As we speak of a steam-engine as a heat-motor, so we might speak of most water-motors as gravity-motors.

However, using the term water-power as a convenient one, it may be pointed out that, though a good deal of water-power is already utilized in this country, and though a few motors of very considerable power exist here, it is on the Continent and in America, where coal is dearer, that the most striking instances of the utilization of water-power are to be found. Many members of this Institution have probably seen the turbines at the falls of Schaffhausen, the power of which is distributed to several mills by wire ropes. In the report of the Technical Education Commission there is an interesting account of a visit to Windisch, where 1000 HP. are utilized, the weir and turbines having cost £70,000. At Bellegarde, at the confluence of the Rhone and the Valserine, on a fall of 40 feet, 3,700 HP. are utilized by six turbines, and this amount of power would have been doubled if the project had been commercially successful. Water-power is utilized on a still larger scale in America.

*Holyoke and its Water-power.*—About 18 miles from the mouth of the Connecticut river there was a fall of about 60 feet in a short distance, forming what were called the Great Rapids, below which the river turned sharply, forming a kind of peninsula, on which the city of Holyoke is now built. In 1831 the first mill was erected and driven by water-power. In 1845, the magnitude of the water-power available attracted attention, and it was decided to build a dam across the river. The ordinary flow of the river is

6000 cubic feet per second, giving a gross power of thirty thousand horses, or in dry seasons probably not less than twenty thousand horses. In a recent exceptional summer it seems to have fallen, for a time, to half this amount. The first weir or dam was completed in 1847, but it was carried away. A second dam was built in 1849, with a base of 80 feet and a height of 30 feet. The dam is a timber cribwork filled with stone, and rests on rock. In 1868 it was found necessary to construct an apron to this weir, 50 feet in width. The whole structure is now 130 feet wide, 30 feet above the river bed, and 1,019 feet in length. From above the weir, a system of canals takes the water to the mills on three levels. The first canal starts with a width of 140 feet, and depth of 22 feet. A second canal, parallel through a distance of a mile with the first, takes the water after passing through the mills, and supplies it to a second series of mills. There is also a third canal, at a different level.

With the grant of land for a mill is also leased the right to use the water-power, and the lease of the water-power is transferred to successive tenants with the lease of the mill. A mill power is defined as 38 cubic feet of water per second, during sixteen hours per day, on a fall of 20 feet. This gives a gross power of eighty-six horses, or an effective power, with a good turbine, of about sixty-three horses. The charge for the power is at the rate of 20*s*. per horse-power per annum. Mr. Emerson, from whom I borrow my data, may well say that Holyoke affords the cheapest manufacturing power in the world.

There are numerous other cases in America where water-power is supplied in a similar way at a cost varying from £1 to £5 per HP. per annum. At Bellegarde, I believe, the proposed charge was £8 to £12 per HP. per annum.

The ordinary source of water-power is a supply of water raised by the sun's heat to a convenient elevation, and falling through natural channels back to the sea. On each pound of water, descending H feet, gravity does H foot-pounds of work. We call H the head due to the elevation, meaning by head the energy per pound of water which would be communicated by gravity during its descent, and which is recoverable by suitable machinery.

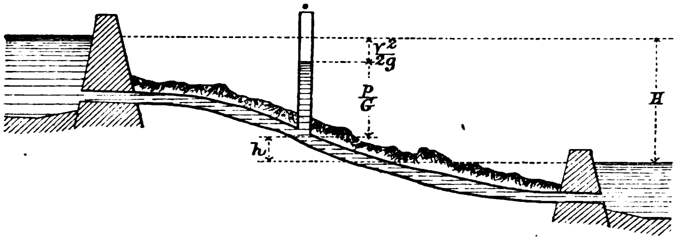
Suppose the water to descend at a uniform rate through a pipe (Fig. 1), which we may imagine frictionless. At any point $h$ feet above the lower level, the water will in general have acquired a pressure $p$ and a velocity $v$. And in that case we know that

$$H = h + \frac{p}{G} + \frac{v^2}{2g}$$

where $h$ is the unexpended part of the fall, $\frac{p}{G}$ is the energy corresponding to the pressure, and $\frac{v^2}{2g}$ the energy corresponding to the velocity of each pound of water. Consequently the head may take three different forms, and, at whatever point of the pipe we make the examination, these three portions of head add up to the same total amount.

Corresponding to each of these three forms which the head takes there is a class of water-motors. By a bucket water-wheel we can recover the energy corresponding to an unexpended part of the

Fig. 1.




fall; by a pressure-engine we can get the energy due to the pressure, and by a turbine we can get the energy due to the velocity.

## I. Bucket- or Cell-Wheels.

First, then, there are bucket- or cell-wheels, in which the water fills the buckets near the top of the fall and descends in contact with the wheel without acceleration.

About this class of motors I have time to say very little. They are simple in principle, and have a fairly high efficiency. But they are somewhat cumbrous and antiquated machines. On falls above 70 feet they cannot be used. On falls of 20 to 60 feet a turbine is cheaper, and yields an equal efficiency. On a low fall, if a turbine costs as much, it has, if well-constructed, a higher efficiency. Still in one respect a good overshot or high-breast wheel is superior to most more modern water-motors. Its efficiency is nearly the same with a reduced supply of water as with the full supply. In this respect many turbines, otherwise excellent, compare very unfavourably with the water-wheel. It is probably because many turbines are not so good as they might be, and because many are extremely bad, that the water-wheel is still constructed, for the falls for which it is most suitable.

## II. Pressure-Engines.

The second way of utilizing water-power is to bring the water to the level of discharge in a closed pipe at small velocity but with a pressure but little less than that due to the height of fall. The water under pressure acts on the piston of a pressure-engine precisely as steam acts in a steam-engine. There are numerous hilly mining districts, especially in Germany, where water-pressure engines are used. Hydraulic lifts and hydraulic cranes in connection with accumulators are pressure-engines driven by an artificially created head of water.

Now although a water-pressure engine is in certain cases a perfectly successful and economical machine, it is not in most cases the best plan to utilize water-power in this way. It may perhaps be instructive to consider why, almost without exception, we use a cylinder and piston with steam and yet only exceptionally resort to the same expedient with water.

The great difference between steam under pressure and water under pressure is this—that one is a comparatively light fluid indefinitely expansible, the other a comparatively heavy fluid, the volume of which is not measurably changed by any ordinary variation of pressure.

The frictional losses of energy in a fluid are proportional to its weight. If, for instance, water is 500 times heavier than steam, then at the same velocities of flow the frictional losses are 500 times greater in the water than in the steam. To prevent enormous waste of energy in friction, a water-pressure engine must be run much more slowly than a steam-engine, and all the pipes and passages for a given volume of flow must be much larger. A steam-engine has a piston speed of 400 or 500 feet per minute; a water-pressure engine rarely has a speed exceeding 80 feet per minute. Steam flows in steam-pipes with a velocity of 100 feet per second, but in the passages of a pressure-engine the velocity of the water does not exceed 4 to 6 feet per second. Hence for a given power a water-pressure engine is much more cumbrous than a steam-engine, except in those cases where the water-pressure is 8 or 10 times as great as is practicable with steam. It is just when an exceptionally high-pressure can be obtained, or requires to be used, that the water-pressure engine is most applicable.

The second difficulty in the use of water in a pressure-engine arises out of its incompressibility. The same volume of water, and consequently, in most cases, the same amount of energy must be

expended each stroke, whether the resistance is great or small. If a hydraulic lift rises, the same volume of water is expended whether the lift is empty or loaded. Where the work is intermittent this disadvantage is often far more than counterbalanced by the other advantages of the use of water. But where the work is continuous the waste of energy is more serious. Suppose a pressure-engine is employed—as it not uncommonly is—in pumping. Then the pressure cylinder must be so proportioned that the work is done when the fall supplying the pressure is lowest and the lift highest. If the fall increases or the lift diminishes no economy of water is realizable, but some prejudicial resistance by throttling must be created to prevent the engine running away and to absorb and waste the surplus energy. Such engines only work with good efficiency with a constant fall and lift, and only then when quite exactly proportioned to the work to be done.

Many years ago Sir W. Armstrong invented the plan of distributing hydraulic power in towns. For doing intermittent work, especially for lifting purposes, the system of hydraulic-pressure mains has proved altogether successful; the most remarkable application being the system of several miles of mains worked at a pressure of 800 pounds per square inch, and successfully laid in the streets of London by Mr. Ellington. Hitherto, however, the system has not proved so useful for ordinary power purposes as was no doubt originally expected. The pressure is too great to be conveniently applied in a turbine, and the pressure-engine in its ordinary form is too extravagant in its consumption of water for ordinary power-purposes.

It has been proposed to admit a variable quantity of water to the pressure-cylinder from the pressure-main, and to complete the stroke with water drawn from a low-level reservoir. The driving effort would then be very irregular, but the plan does not seem impossible. Some years ago Mr. Hastie invented a pressure-engine in which, by very ingenious automatic gear, the stroke of the engine is varied, diminishing when the resistance decreases, and increasing when the resistance increases.

Through the kindness of Mr. Ellington, a drawing is exhibited of an improved "Hastie" engine, which is being introduced for power-purposes in London. The engine has fixed cylinders, on the plan of the "Brotherhood" engine, and the spring gear which alters the stroke is much simpler than in the original engine.

There are other peculiarities in the action of water-pressure engines which arise out of the weight and incompressibility of the acting fluid. In the first place, the whole column of water

between the pressure-cylinder and the supply reservoir virtually forms part of the piston of the engine, so that a water-pressure engine is in general an engine with a very heavy piston. The effect of the inertia of the piston is very well understood. It tends to make the effective effort transmitted smaller than the pressure on the piston in the first half of the stroke, and greater than the pressure on the piston in the second half of the stroke. In a steam-engine this is often an advantage. The diminution of steam-pressure, due to expansion, can be in great part neutralised by the effect of the inertia of the piston. At any rate the inertia of the piston generally tends to diminish the inequality of the driving effort. It is otherwise with a water-pressure engine, in which the water-pressure, being constant, the effect of inertia is to render the driving effort variable; and this is so much the less advantageous, because while with the light fluid steam we can neglect the weight of the fluid, with water we must reckon the weight of water in the supply-pipe as forming part of the piston.

I believe that the precise part played by the inertia of the water in the motion of a pressure-engine has first been indicated by Professor Cotterill in his Treatise on Applied Mechanics. He has specially treated of the case of a rotating engine, while I shall consider rather those pressure-engines which make a stroke, uncontrolled by a crank and fly-wheel. In such engines the inertia of the fluid behind the piston tends to produce an acceleration of velocity and shock at the end of the stroke, which in general can only be prevented by means which reduce the efficiency of the engine.

In a very early water-pressure engine of Trevithick's, the piston-valve was made less in length than the width of the port, so that for a short period the supply-pipe was directly open to the exhaust, the flow being gradually arrested by wire-drawing as the valve closed. This involves very great waste. In later engines the valve closes somewhat gradually towards the end of the stroke, so as to retard the flow. But the resistance thus created absorbs and wastes most of the kinetic energy of the water in the supply-pipe.

We diminish the difficulty due to the inertia of the moving mass of water by very much restricting its velocity. It is mainly on account of the inertia of the water that while steam-engines are run at 400 to 600 feet of piston speed per second, water-pressure engines are rarely run at more than 60 to 80 feet per minute.

There are certain cases in which the friction and inertia of the fluid, which in most cases are prejudicial, render essential service in the working of the machine. The friction increasing as the square

of the velocity acts as a brake in preventing the velocity from becoming excessive, and the diminution of the effective effort at the beginning of the stroke, and its increase at the end of the stroke, which is due to the inertia of the fluid column, is extremely advantageous in certain operations.

All Members of this Institution will be acquainted with Mr. Tweddell's admirable hydraulic riveting and punching machinery. It is well known that those machines work not only very efficiently in the sense of doing their work well, but they work with a smaller expenditure of power than machines driven by gearing. That is due partly to saving the friction of the gearing, but mainly to the fact that the machines make no waste strokes. They do not keep on running while waiting for work. On the other hand, in the actual working-stroke there is a proportionately large loss of work.

Fig. 2.

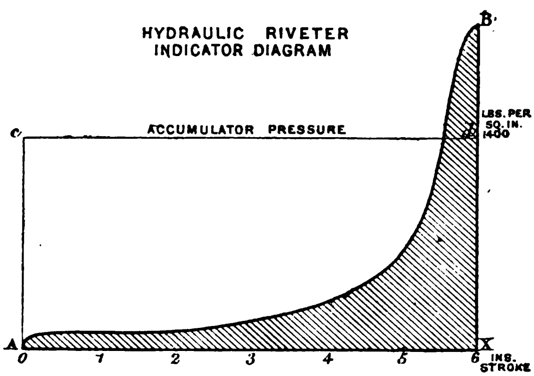
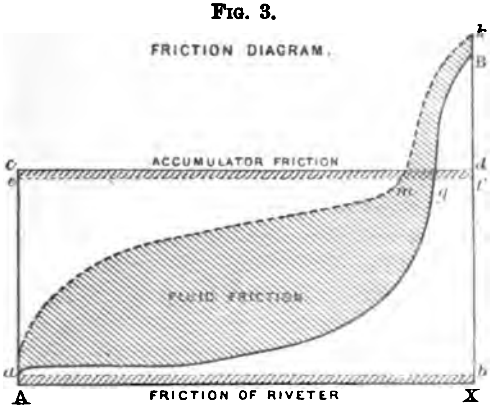



Fig. 2 shows a diagram from a riveter driven by a differential accumulator through 30 feet of 1-inch pipe. The water in the pipe accelerates and is retarded proportionately to the movement of the riveter ram, and the accumulator weight also accelerates and retards in the same way. Hence the water in the pipe and the accumulator weight virtually form part of the moving riveter ram. But as the accumulator weight moves six times as fast as the riveter ram, the forces due to its inertia are thirty-six times as great as if it were attached to and moved with the riveter ram; and as the water moves eighty-one times as fast as the ram, the forces due to its inertia are more than six thousand times as great as if the water moved at the same speed as the ram. In this machine, therefore, the virtual weight of the ram which closes the rivet, and which is put in motion and stopped every stroke, is 300 tons.

To control the movement of such a mass as this, powerful brake-action is necessary, and Mr. Tweddell's brake is supplied by the automatic action of the water-friction.

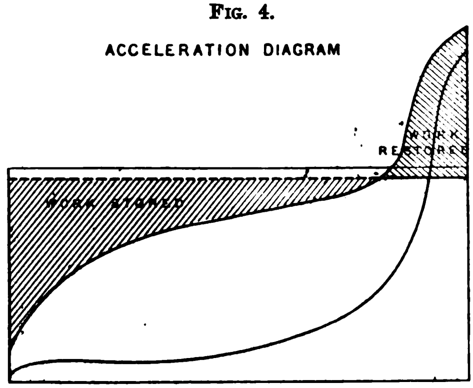
On looking at the diagram, Fig. 2, it will be seen that the effect of the inertia is to greatly diminish the pressure in the beginning of the

FIG. 3.




stroke, and to increase it above the accumulator-pressure at the end of the stroke. That is advantageous in closing the rivet. But a large part of the diagram is missing; apart from friction and inertia the diagram would be a rectangle A *c d* X. The actual pressure-line falls greatly below this. Fig. 3 shows an estimate of the

FIG. 4.




friction. There are two rectangles, A *a b* X and *e c d f*, showing the uniform friction of the cup leathers of the riveter and accumulator rams, and there is a surprisingly large area *a m k* B *g* representing the friction of the water in the 1-inch pipe. In fact, it

is this friction which determines the speed of the machine, and keeps it down to the safe limit of about 1 foot per second at most. When the friction diagram is added to the diagram of useful work, we see that the unbalanced or stored work in the first half of the stroke *a e m* is nearly equal to the excess of work *m k f* at the end of the stroke, so that the machine comes to rest without any violent shock. Mr. Tweddell's riveter is virtually a 300-ton hammer, controlled by a powerful automatic friction brake. Fig. 4 shows better the work stored in the first part of the stroke, and re-stored in the second.

## III. Turbines.

There are motors, of which the undershot wheel is an old type and the turbine a modern type, in which the head is allowed to take the third form before acting on the motor. On undershot wheels and turbines the water acts in virtue of its velocity. Let the water acquire a velocity due to the head in a given direction. Then the water, by its inertia, opposes change of velocity and direction. In the class of wheels now discussed, the water gives up its energy through this action of its inertia. We have now to study under what conditions we can best recover the energy of motion of the water.

Of the whole energy expended by the water on the machine, a part is taken up and utilized, another part is wasted or lost. It is the object of the designer to make the latter part as small as possible, and it is therefore necessary to consider in what ways this loss or waste of energy may arise.

1st. There is a waste of energy if the water is allowed to break up into eddies or irregular motions. When water breaks up in this way we say there is loss by shock.

2nd. The water leaving the machine may carry off with it part of its energy, there is then a waste of unutilized energy. In many motors this loss is a large one. In the class of motors now considered, this energy rejected can be made as small an amount as we please.

3rd. In flowing over the solid surfaces of the machine, there is what is termed fluid or skin friction. This is really a loss of the same kind as that due to shock, because skin friction arises from the production of small eddies against the roughnesses of the solid surfaces, or from instability in the fluid itself.

There are some smaller losses due to leakage, friction of bearings, and so on, which for the purpose of this lecture may be treated as negligible.

*Losses due to shock or breaking-up.*—If water is poured from a height into a basin, it acquires in falling energy of motion. Reaching the vessel it is dashed about in different directions and broken up into eddying masses. In a short time the friction destroys this irregular motion, and the energy is wasted.

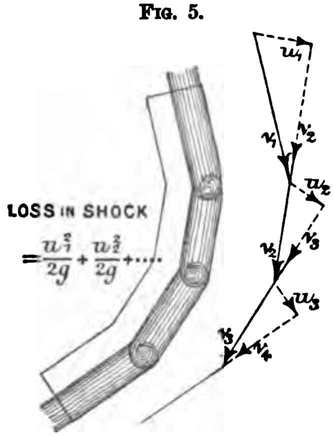
There is generally such a breaking-up of the fluid and waste of energy if the direction of motion or velocity of a fluid stream is abruptly changed.

Let the water be moving along a pipe which changes section abruptly. Then the velocity $v_1$ in the first part is changed to $v_2$ in the second. At the abrupt change of section, eddies are continually formed which carry off part of the energy of the fluid in a useless form. The energy thus subtracted from the energy of translation, and for practical purposes lost, is—

$$\frac{(v_1 - v_2)^2}{2g}$$

For example, if the section of the pipe is doubled, the loss of energy is one-fourth.

FIG. 5.




So much for abrupt change of velocity. Next consider abrupt change of direction. To make the problem quite simple, suppose the water flowing round a bent trough A B C D, Fig. 5. At each bend eddies will be formed at the expense of the energy of flow along the surface. Resolve $v_1$ at A into a component $v_2$ parallel to A B and a normal component $u_1$. Then the energy corresponding to $u_1$ is wasted, and the water proceeds along A B with the velocity $v_2$. Resolve $v_2$ at B into a component $v_3$ parallel to B C,

and a normal component $u_2$. Then $u_2$ is wasted. Thus for the whole surface, there is wasted for each pound of water—

$$\frac{u_1^2}{2g} + \frac{u_2^2}{2g} + \frac{u_3^2}{2g} + \ldots\ldots$$

Now notice the velocities $u_1$, $u_2$, $u_3$, depend on the angles at the bends, and vanish if those angles are indefinitely small. Hence, if the surface is curved throughout, there is no loss due to breaking up, and the water flows round with its velocity unchanged, except so far as there may be a very small loss due to the friction of the surface.

Hence the second condition for avoiding loss in dealing with streams of water is, that the surfaces over which it flows should be gradually and regularly curved.

Generally in hydraulic motors we have to deal with fixed jets of water impinging on moving curved vanes. The condition of avoiding loss due to abrupt change of direction imposes a third very important condition as to the direction of the vane where the jet first impinges. Let A B be the fixed jet of water, B C the moving vane. Let $v_2$ be the velocity of the jet, and $u$ the velocity of the vane. Resolve $v_2$ into a component $u$ equal and parallel to the velocity of the vane, and a relative component $v_r$. Then if the tangent to the vane at B is parallel to $v_r$, there is no change of direction when the water first impinges on the vane, and no loss due to eddies or breaking up.

These three conditions—gradual change of section, gradual change of curvature of the surfaces, and the inclination of the receiving edge of the vanes in the direction of relative motion—can always be satisfied, and hence there need be no loss in an hydraulic motor due to the shock or breaking up of the fluid.

The two other sources of loss in an hydraulic motor, the energy carried away, and the skin-friction against the surfaces of the motor, are not so easily disposed of. We can indeed reduce the energy carried away almost as much as we please. If there were no skin-friction, turbines might have any efficiency short of 100 per cent. The energy carried away in good turbines is often not more than 6 per cent. But it might be reduced to 3 per cent. or 1 per cent., only in doing this, we should in general seriously increase the loss from skin friction.

It is this loss from skin friction which regulates the proportions of turbines, and which compels us to use, in many cases, small and high speed turbines on high falls. The writer erected a 70-HP. turbine on 250 feet fall, with a wheel 15 inches in diameter, making 1500 revolutions per minute. The skin friction of the disks of

this turbine probably amounted to 4 HP. If the diameter had been doubled to reduce the speed to 750 revolutions, the skin friction would probably have amounted to 16-HP.

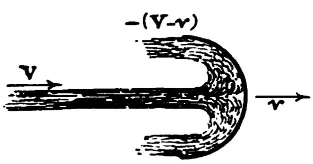
Before considering the more complex case of turbines, it will be convenient to examine one or two simpler cases in which these principles are applied.

Consider first the old form of undershot waterwheel. The water issuing under a sluice with nearly the whole velocity due to the head, strikes the radial floats. There is a loss due to breaking up, and as the water flowing away cannot have a less velocity than the wheel, there is a large amount of energy rejected. Under the best conditions when the wheel has half the velocity due to the fall, 25 per cent. is lost by shock, and 25 per cent. rejected into the tail-race. So that apart from the losses by friction and leakage, an undershot wheel utilizes less than half the energy of the fall.

Many years ago General Poncelet recognized the causes of loss in the ordinary undershot wheel, and constructed the well known Poncelet wheel. I pass over this to examine another less known example of a wheel of this type.

If a jet strikes a hollow cup larger than itself, there is little loss due to breaking up, the jet spreading symmetrically. The water spreads with the relative velocity $V-v$, which is reversed in direction at the lip and becomes $-(V-v)$, so that the absolute velocity of discharge is $-(V-v)+v=2v-V$. By making $v=\frac{1}{2}V$, the water leaves the cup with no energy left, that is all the energy of the jet is expended on the cup.

FIG. 5A.




Now to supply the Placer mines in California, canals or "ditches" have been built high on the slopes of the Sierra Nevada. These deliver water at an elevation of 1000 to 3000 feet above the great valley of California. In many cases the mines have been exhausted or abandoned, and hence has arisen the idea of using the water power, amounting in the aggregate to several 100,000 horse-power, for mills or quartz crushing.

The fall is here excessively great, and if it were attempted to use turbines, especially those forms most in favour in America, there would be the inconvenience that the turbines would run at an immoderate, and in some cases an unmanageably great speed. This has the double disadvantage of involving great wear and tear, and of requiring a large amount of gearing with its concomitant frictional waste.

About twenty years ago there was introduced a form of impact wheel which, with American talent for nicknames, was called the Hurdy-Gurdy. It consisted of a wheel of considerable diameter with a series of cast-iron floats 4 to 6 inches wide on the face. A jet of water of very small diameter (three-eighths of an inch sometimes) was allowed to strike the vanes normally. Theory shows that in this case the wheel should run at half the speed of the jet, and that the efficiency, even apart from friction, could not exceed 50 per cent. Practical experience also showed that the wheel should have half the velocity of the jet, and the efficiency was found by experiment to be 40 per cent. In spite of the low efficiency, such wheels seem to have been useful, partly because they were cheap and free from any liability to accident, but mainly, probably because, by choice of diameter of wheel, any convenient speed of rotation can be obtained.

It is easy to see that the efficiency could be improved by substituting cups for flat floats, and this is what has actually been done. The favourite wheel now is a wheel termed the Pelton wheel, the floats of which are simply cups which deviate the water backwards. A wheel of this kind, working to 107 HP. under a head of 386 feet, is said to have given an efficiency of 87 per cent. Without accepting exactly this figure, I see no reason why, with a very high fall, an efficiency of 80 per cent. at all events should not be reached.

At the Idaho mines, seven of these Pelton wheels have recently been erected to work to about 320 HP., driving machinery previously driven by steam. The water is brought a distance of 9000 feet in a thin wrought-iron riveted main, 22 inches in diameter. The total head is 542·6 feet, reduced by friction in the main to an effective head of 523 feet. The nozzles by which the water is delivered to the wheels are from $\frac{1}{1}\frac{5}{6}$ to $1\frac{1}{1}\frac{5}{6}$ inch in diameter and the power is taken from the wheels by 2-inch Manilla ropes in grooved pulleys. The cost of the change from steam to water-power was between £10,000 and £11,000. The wheels work with hardly any attention or wear, and are believed to give 80 per cent.

### The Jet Reaction-Wheel or Scotch Turbine.

There is a very simple form of reaction-wheel which forms a convenient step towards a true turbine. In this the water enters the centre of the wheel, spreads radially, and issues in jets tangentially to the direction of revolution. The water issues under the head $h$ due to the fall and $\frac{v^2}{2g}$ due to the centrifugal

force of the mass of water in the wheel. Let V be the velocity of the wheel, then the velocity of the water through the orifices is

$$v = \sqrt{2gh + V^2}$$

and the backward velocity of the water at the jets is

$$v - V = \sqrt{2gh + V^2} - V$$

It is obvious that this approaches zero as V approaches infinity. For any smaller speed, part of the energy of the fall is rejected into the tail-race in the backward motion of the water. Taking friction into account, the best speed of the wheel is the velocity due to the head, and then about 17 per cent. of the energy is carried away, and another 10 or 15 per cent. is lost in friction.

Now it was the study of the source of the waste of energy in this wheel which led Fourneyron to the invention of the turbine. Fourneyron perceived that in order to avoid the loss due to the backward velocity of discharge, an initial forward velocity must be given to the water. By putting the water in rotation forwards by fixed guide-blades before it enters the revolving wheel, the backward velocity of discharge can be made as small as we please, and then the efficiency of the turbine may approach 100 per cent. as nearly as we please, apart from the frictional losses, which can in no case be prevented.

The Scotch turbine would from its simplicity be still used in certain cases, but for two serious practical defects. One is that it is the most unstable in speed of all turbines; the other is that it admits of no efficient mode of regulation for a variation of water-supply.

At the beginning of this century there existed a number of horizontally rotating water-wheels, driven by jets of water, or by rotating masses of water, which acted on them chiefly by their inertia. The efficiency of these was very low. In some treatises, especially those of Euler, there were indications of the true principles of construction of such a motor. But it was Fourneyron in 1827 who first realized a practical turbine. Fourneyron received the prize of 6,000f. for his invention from the Société d'Encouragement. His turbine is still sometimes constructed with very little modification, and its essential features are present in turbines of all constructions.

Fourneyron perceived that if the water was to leave the wheel without any backward velocity, that is without carrying away and wasting energy, the water must have given it some initial forward velocity before entering the wheel, and his invention

mainly consisted in the introduction of guide-blades to give that initial forward velocity.

In the Fourneyron turbine, the water descending into the centre of the wheel is put into rotation by the guide-blades, and passes into the wheel with a velocity rather less than that due to the head. It passes through the wheel radially and outwards, and hence the Fourneyron turbine is called an outward-flow turbine. The great defect of the Fourneyron turbine is the practical difficulty of constructing any good form of sluice for regulating the power of the turbine. With the cylindrical sluice ordinarily used between the guide-blades and wheel, the efficiency falls off rapidly as the supply of water is diminished, and it is this practical difficulty which I think is leading to a general abandonment of the Fourneyron turbine.

The Fourneyron turbine was soon succeeded by the Jonval turbine, in which the water flows parallel to the axis of the turbine. The Fourneyron turbine works best above the tail water. The Jonval turbine has the advantage that it can be placed below the tail water, or at any height less than 30 feet above it with a suction-pipe. But its sluice arrangements are even worse than those of the Fourneyron turbine.

Lastly Professor James Thomson introduced an inward-flow turbine, in which the water flows radially inwards and is discharged at the centre of the wheel. The greatest advantage of this arrangement is that a perfect system of movable sluices or guide-blades can be adopted to regulate the power of the turbine, there being ample space to arrange these outside the wheel.

There are therefore outward-flow, inward-flow, and axial or parallel-flow turbines. To these must be added a form used by the late Mr. Schiele, in which the water flows inwards radially and afterwards axially, the wheel-vanes being prolonged nearly to the centre of the wheel, and which may be called a mixed-flow turbine.

Now in all these turbines, and in all modifications of them constructed for many years, a peculiarity of proportion originally adopted by Fourneyron was followed. Instead of allowing the water to issue from the guide-blades with the whole velocity due to the head, he so proportioned the passages that there was a more or less considerable pressure in the space between the guide-blades and wheel. All these turbines are therefore pressure-turbines, that is turbines in which the water enters the wheel under pressure.

To maintain this pressure properly two conditions are necessary,

the wheel passages must be completely filled with the stream of entering water, and consequently the wheel must receive the water continuously over the whole circumference simultaneously. These are therefore turbines with complete admission.

Mr. Girard was the first to perceive clearly the advantage of departing from Fourneyron's practice. Mr. Girard constructed turbines in which the water issued from the guide-blades with the full velocity due to the fall, and therefore with no pressure. The wheel must be placed entirely out of the tail water, so that the issuing water is freely deviated on the curved vanes of the wheel. Nearly the whole energy of motion of the water less the loss in friction is given up to the wheel. Turbines of this kind are called turbines of free deviation or impulse-turbines.

Impulse-turbines may be inward-, outward-, or parallel-flow turbines, but they are very commonly outward-flow. For normal conditions of working they are slightly less satisfactory than pressure-turbines, but they have two very great practical advantages.

In a pressure-turbine there must be a definite rate of flow through the wheel to maintain the exact distribution of pressure in the wheel for which it is calculated. If the guide-blade passages are partially closed the distribution of hydraulic pressure is completely altered, and the efficiency reduced. In the turbine of free deviation, on the other hand, there is no possible change of pressure in the wheel, for it is all open to the air. Each particle of water following the curve of the wheel-vane acts by itself alone without any interference from its neighbours. Hence if the guide-passages are partially closed the stream on the wheel is rendered thinner, but its efficiency is in no way impaired. Hence the regulation of the Girard turbine is in general far more perfect than in a pressure-turbine.

## Classification of Turbines.

### I.—*Impulse Turbines.*

Wheel passages not filled.
Free deviation.
No pressure between guide passages and wheel.
Discharge above tail-water.

*a.* Complete admission.
*b.* Partial admission.

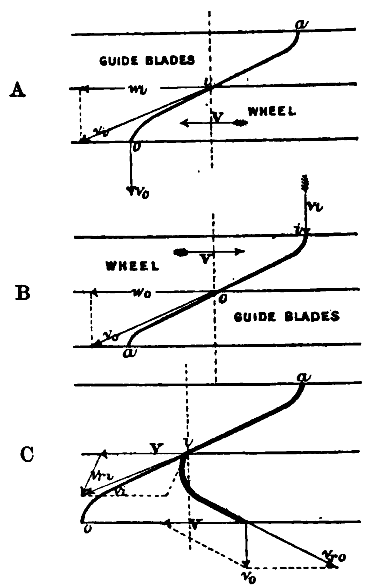
Axial-, inward- or outward-flow.

## II. *Pressure- or Reaction-Turbines.*

Wheel-passages filled.
Pressure between guide-blades and wheel.
Discharge above tail-water (outward flow); or below tail water (parallel or inward flow); or into suction-pipes (parallel or inward flow).
Always complete admission, axial, inward, outward, or mixed (inward and downward) flow.

To simplify the consideration of the action of the water in a turbine, suppose that for a turbine wheel moving circularly we substitute a turbine rod moving in a straight line.[1] We can pass to the case of the wheel easily afterwards. To be definite, suppose the water flowing vertically downwards, and the rod (Fig. 6 A) moving horizontally from right to left. To give the initial necessary forward velocity the water must be deflected in some path *a i* by fixed guide-blades. Entering the wheel it produces pressure due to deviation by the wheel vanes, and traverses a path *i o* leaving the

FIG. 6.




[1] The development of a section of an axial-flow turbine has always been treated in this way, but the use of a turbine rod as the first step in designing any turbine is due to Von Reiche.

wheel finally with a much reduced velocity in a direction normal to the surface of discharge.

A simple application of Newton's second law of motion gives at once the force driving the wheel. The water enters the wheel with the initial velocity $v_i$, which has the horizontal component $w_i$, and leaves the wheel with a velocity which has no horizontal component. Each pound of water per second therefore loses the horizontal momentum $\frac{w_i}{g}$, and since impulse is equal to change of momentum, the horizontal pressure on the wheel is

$$\frac{w_i}{g} \text{ lbs.}$$

for each pound per second flowing through the wheel, and the useful work done in driving the wheel is

$$\frac{w_i \mathrm{V}}{g} \text{ foot-lbs. per second.}$$

But the whole energy of gravity on each pound of water falling H feet is H foot-pounds. Hence if $\eta$ is the efficiency,

$$\eta \mathrm{H} = \frac{w_i \mathrm{V}}{g}.$$

This is the fundamental equation on which the whole design of turbines depends. It gives the relation between the original whirling velocity of the water and the velocity of the wheel.

I stop for a moment to point out that exactly the same result is arrived at if the position of the wheel and guide-blades is inverted as in Fig. 6, B. Then the water having no initial forward momentum gains the momentum $\frac{w_o}{g}$ in the wheel, and the equation becomes

$$\eta \mathrm{H} = \frac{w_o \mathrm{V}}{g}.$$

In applying this formula the fall H is the effective fall, that is the fall after deducting any losses in the supply-pipe tail-race, &c., which are extraneous to the turbine. From the work $\eta$ H really utilized by the turbine an additional small loss occurs in the transmission, from friction of the shaft, friction on the wheel covers, and friction of gearing.

It is now to be seen what forms the guide-blades and wheel-vanes must have to direct the water in the absolute path chosen for it.

The guide-blades, being fixed, have exactly the form of the

chosen water-paths *a i*, Fig. 6, A, or *o a*, Fig. 6, B. But the wheel-vanes have a quite different form from the water-path, because as water moves along that path the wheel also is moving.

In order that the water may enter the wheel without shock the first element of the vane must be parallel to $v_{r\,i}$, Fig. 6, C, the direction of relative motion. In order that the final velocity of the water may be vertical the last element of the wheel-vane must be parallel to $v_{r\,o}$, obtained by compounding the final velocity $v_o$ with the velocity V of the wheel. Having obtained the tangents to the two ends of the wheel-vane, any smooth curve joining these two will satisfy the necessary conditions for the proper action of the water.

### *Turbine-Rod corresponding to a Girard or Impulse Turbine.*

In the Girard turbine there is no pressure in the clearance space, and therefore the water issues from the guide-blades with the velocity due to the effective fall. In the diagram

$$v_i = 0\cdot 95 \sqrt{2\,g\,\mathrm{H}}$$

which allows for the friction of the guide-blades.

FIG. 7.

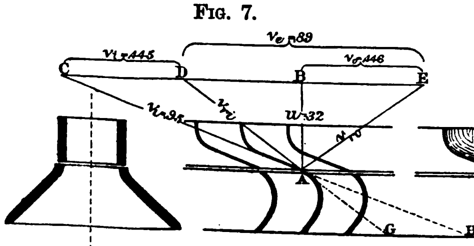
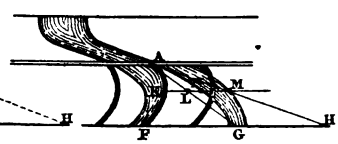



FIG. 8.




Cross-section.

GIRARD TURBINE.
$h = 29\cdot 5$;
$\sqrt{2\,g\,h} = 43\cdot 6$;
$\eta = 0\cdot 89^2 = 0\cdot 79$.

Next decide what energy shall be rejected into the tail-race. Suppose this is put at 10 per cent., the velocity corresponding to one-tenth of the fall is

$$u = 0\cdot 32 \sqrt{2\,g\,\mathrm{H}.}$$

Draw now the triangle of velocities C A B, so that $u$ is the vertical component of $v_i$. Then C A is the direction in which the water enters the wheel.[1]

[1] It is assumed here that the velocity of flow through the wheel, $u$, is constant. If it is not so, the figure must be drawn with the actual values.

Bisect C B in D. Then C D is the proper velocity of the wheel, and A D is the direction of relative motion of the water and wheel, and tangent to the first element of the wheel-vanes.

In an impulse turbine the relative velocity remains unchanged. Set-off B E = the velocity of the wheel, then A E, which obviously by construction is equal to D A, is the direction of relative motion of the water leaving the wheel, and the tangent to the last element of the wheel-vanes.

We have now determined all three angles necessary for drawing the guide-blades and wheel-vanes.

Further, since the relative velocity $v_{r\,i}$ is changed to $v_{r\,o}$ in passing through the wheel, therefore D E or $V_e$ is the velocity utilized in the wheel. Hence the work utilized is

$$\frac{V_e^2}{2\,g},$$

and the efficiency of the wheel is $0 \cdot 89^2 = 0 \cdot 79$, apart from those losses which are extraneous to the turbine itself.

To secure the free deviation of the water on the wheel-vanes, and to prevent the choking of the wheel-passages, it is usual to flare out the wheel as shown in the cross-section. Very commonly the ratio of the inlet and outlet widths is as 4 to 7.

Every datum for the turbine which depends on hydraulic considerations has therefore been determined. And any one who has mastered this very simple diagram, and who has the requisite general mechanical knowledge, can design a turbine, I need not say as well as I could, but as well as Mr. Girard himself could.

In drawing the stream of water on the vane it is merely necessary to remember that the relative velocity is constant, and therefore the thickness of the water-sheet is inversely as the width of the bucket.

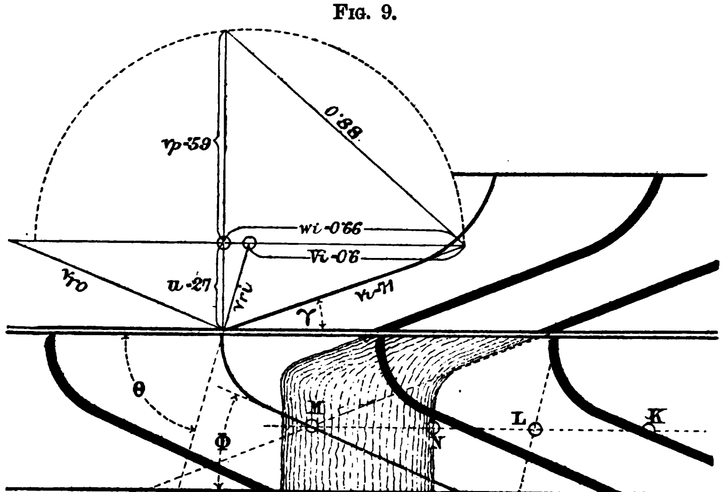
It is useful to examine the exact absolute path of the water in the wheel, which is easily obtained. If there were no wheel-vanes the water would traverse the absolute path A H and the relative path A G. But the wheel-vanes deviate the water the distance L K from A G. Set-off M N = L K, then N is a point in the absolute path. Any number of such points can be found and the absolute path drawn. Or conversely, if the absolute path is chosen the wheel-vane can be drawn. The wheel-vanes will be of good form if the absolute path shows a continuous and tolerably uniform curvature, and if the water-stream through the wheel is a converging rather than a diverging one.

TURBINE ROD CORRESPONDING TO A PRESSURE-TURBINE.

In a pressure turbine the wheel passages are always full. Hence the velocity of flow, that is, the vertical component of the waters' velocity in the diagram is constant, or at all events is determinable from the general dimensions of the wheel. That velocity is, therefore, the velocity at which the water is rejected into the tail race. This ought to be small; it is very often only $\frac{1}{8}\sqrt{2\,g\,H}$, but to make the diagram clearer, I have taken it at $0\cdot27\sqrt{2\,g\,H}$, in which case 7 per cent. of the energy is rejected.

Further, 8 to 15 per cent. of the energy is wasted in friction. Taking the extreme case—suppose 15 per cent. wasted in friction; then there remains 78 per cent. to be utilized in the turbine, and the velocity due to 78 per cent. of the head is $0\cdot88$ of the velocity due to the head.

FIG. 9.




JONVAL TURBINE.

In a pressure-turbine this 78 per cent. of the energy is partly used in producing the initial horizontal velocity, and partly in producing the pressure in the clearance space. It is optional, how this division is made. In the figure the velocity $0\cdot88$ is divided into a horizontal component $w_i = 0\cdot66$, and a vertical component $0\cdot5v_p = 89$. Hence, if the initial horizontal velocity is taken at $0\cdot66\sqrt{2\,g\,H}$, the velocity corresponding to the pressure in the clearance-space will be $0\cdot589\sqrt{2\,g\,H}$.

Setting off the assumed vertical velocity 0·27, and the just found horizontal velocity 0·66, we get the initial velocity and direction of motion of the water $v_i = 0 \cdot 71 \sqrt{2\,g\,\mathrm{H}}$, and determine the angle $\gamma$ of the guide-blades.

To determine the proper velocity of the wheel, I shall apply the principle of momentum. As the water enters the wheel with the horizontal velocity $w_i = 0 \cdot 66 \sqrt{2\,g\,\mathrm{H}}$, and leaves with no horizontal momentum, the effective horizontal pressure of each pound of water on the wheel is

$$\frac{w_i}{g} \text{ lbs.}$$

and if V is the velocity of the wheel, the useful work done is

$$\frac{w_i\,\mathrm{V}}{g} \text{ ft.-lbs. per pound of water.}$$

But 78 per cent. of the energy due to the head is utilized so that

$$\frac{w_i\,\mathrm{V}}{g} = 0 \cdot 78 \text{ H},$$

which gives

$$\mathrm{V} = 0 \cdot 78 \frac{g\,\mathrm{H}}{w_i} = 0 \cdot 78 \frac{g\,\mathrm{H}}{0 \cdot 66 \sqrt{2\,g\,\mathrm{H}}}$$

$$\mathrm{V} = 0 \cdot 6 \sqrt{2\,g\,\mathrm{H}}$$

Knowing V and $v_i$, we have now the direction of relative motion where the water enters the wheel, and the angle $\theta$ of the first element of the wheel-vanes.

Similarly combining $u$ and V, we get the relative velocity $v_{ro}$ at the point of discharge, and the angle $\phi$ at the other end of the wheel-vanes.

It is easy to show that the utilized velocity 0·88 is the chord of a semi-circle, of which the velocity V of the wheel is the radius, so that the velocity of the wheel is easily found graphically and without calculation.

*Transformation of the Turbine-Rod into an Inward- or Outward-Flow Turbine.*—It is not difficult to proceed by methods similar to those already described to draw directly the path and the curves of the vanes of a radial flow turbine. But the proceeding is complicated by the circular motion, and a more simple method is available. If we draw a turbine rod for any given case first, the corresponding inward or outward flow turbine can be obtained by simple geometrical projection.

Draw circles at the same distances apart as the edges of the

guide-blades and wheel in the turbine rod. Subdivide the spaces of the turbine-rod by lines at equal distances, and the spaces of the turbine by corresponding equi-distant circles. Thus let the circle *b* correspond to the line *b* in the turbine rod. Project the point where *b* intersects the wheel-vane to the circle *a*, and draw a radius. Where this intersects the circle *b* is the corresponding point on the wheel-vane curve. The guide-blade and absolute water-path are projected in the same way.

*Efficiency of Turbines.*—The largest waste of energy in turbines is due to fluid friction, and this cannot be estimated with any great accuracy, and can only therefore be determined by experiment.

There are a number of experiments, too carefully carried out and too accordant to be put aside, which show that turbines of very different types, well constructed, and working in the best conditions, yield an efficiency little if at all inferior to 80 per cent. A very few experiments, apparently also reliable, show an efficiency slightly greater. But allowing for the probabilities of error in water measurement, I think that 80 per cent. may be taken as the maximum efficiency of the best turbines in normal conditions of working.

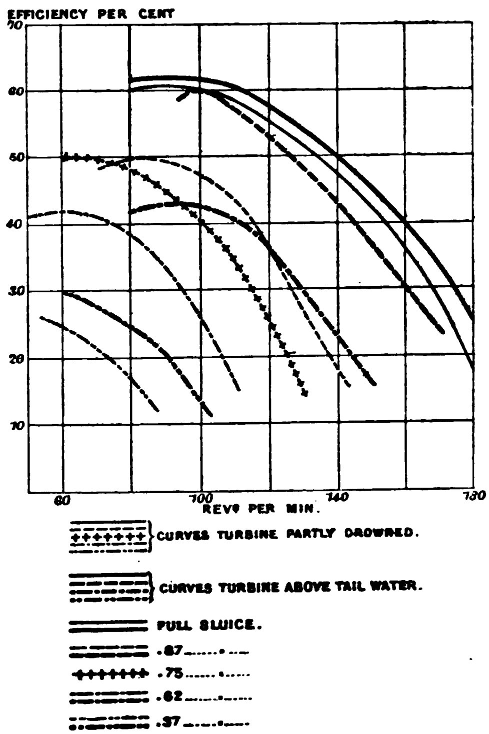
While I do not believe that this efficiency is likely in any case to be exceeded, I believe also that any one of the ordinary types of turbine will, within a very small range of difference, yield the same efficiency. The search of inventors, especially in America, for some new modification of the turbine, which shall have a greater maximum efficiency, I believe to be altogether a chase of the philosopher's stone, and not likely to end more successfully than that of the Rosicrucians.

The statements that this turbine or that has attained 82 or 83 or 85 per cent. of efficiency are not only delusive, they are extremely misleading. The probability is that the small extra percentage of maximum efficiency claimed over that of other turbines is due to error of water measurement. But even if this is not the case, the real practical value of a turbine is not measured by its maximum efficiency when everything has been arranged to suit it, but by the average efficiency in the varying conditions of fall, water-supply, speed, and work to be done, in which it has actually to operate. Now there is one condition, at all events, which in most turbines is constantly varying. The supply of water varies either from actual deficiency in the supply, or because the work to be done varies. In either case the quantity of water discharged through the turbine varies. To effect this alteration of discharge, turbines are provided

with sluices or regulating apparatus. In nearly all cases the use of the regulating apparatus seriously diminishes the efficiency of the turbine, so that the average efficiency is very much lower than the maximum efficiency. In the mode of regulating different turbines, there are differences far more important than any difference of type or mode of action. Before discussing the efficiency of turbines under regulation, there is a preliminary point to clear up.

Some eighteen years ago I plotted the curves shown in Fig. 10,

FIG. 10.

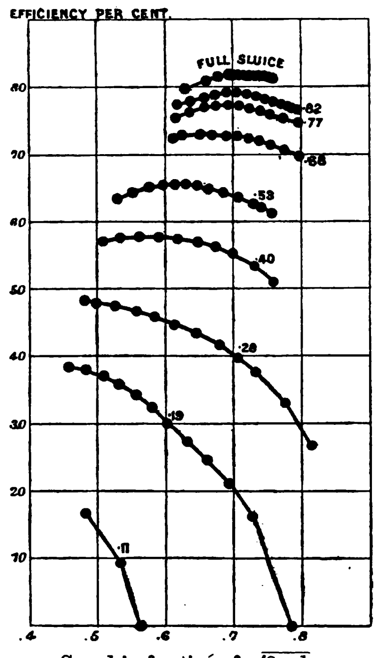



giving the efficiency of a Fourneyron turbine, with different sluice-openings and at different speeds. There are two sets of experiments, shown by darker and thinner lines, corresponding to the normal condition for a Fourneyron out of water, and to the case where the turbine was partly drowned. Roughly, the greatest efficiency, when the turbine was not drowned, was 62 per cent. with full sluice, 60 per cent. with seven-eighth sluice, 43 per cent. with five-

eighth sluice, and only 30 per cent. with three-eighth sluice. With the turbine drowned the efficiencies were lower.

For each set of experiments the efficiency is greatest for a given speed of the turbine. But, unfortunately, the speed of greatest efficiency is not the same for different openings of the sluice. With full sluice the efficiency is greatest at about one hundred revolutions. But with three-eighth sluice the efficiency is greatest at sixty revolutions or less. Now, generally the speed of a turbine depends on the work to be done, and cannot be adjusted to suit

Fig. 11.

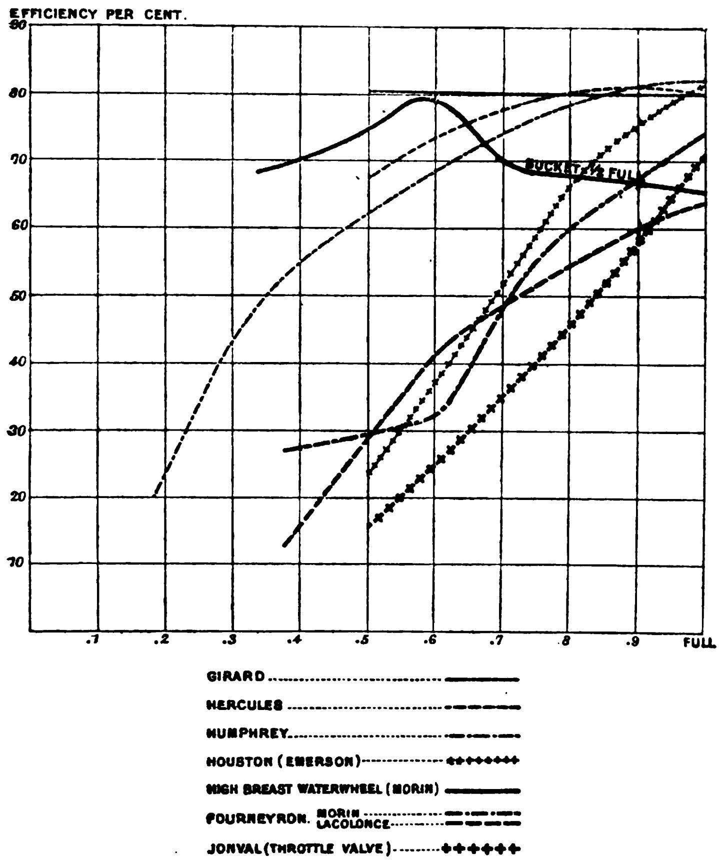



Speed in fraction of $\sqrt{2gh}$.

hydraulic requirements. If the speed has to vary, as in pumping, with the demand for water, the speed will very commonly differ from that which suits the turbine best, and the efficiency will not, on the average, reach the maximum value. Still more commonly a turbine has to drive machinery at a very nearly constant speed. Naturally, we choose for that speed the speed of greatest efficiency with full sluice. But then for that speed the efficiency falls off much more rapidly with the closing of the sluice than I stated before.

Fig. 11 shows the results of a very extensive series of experiments on the Humphrey turbine, carried out by Mr. Francis at Lowell. The turbine is of 275 HP., on 13 feet fall. The experiments were independent of the manufacturers, and the arrangements for water-measurement and power-measurement were as good as possible. They show the rapid falling-off of the efficiency

FIG. 12.




as the sluice closes, and the diminution at the same time of the speed of greatest efficiency. The fraction of sluice open is printed against each curve.

Fig. 12 shows the efficiency of different types of turbine for different openings of the sluice, and always for the speed of

greatest efficiency with full sluice, and is intended to indicate the importance of adopting a good method of regulation.

The worst mode of regulation of all, though it is still frequently used, is to put a throttle-valve in the supply-pipe. A throttle-valve acts entirely by creating a prejudicial resistance, or by destroying part of the effective head.

Next worst to this, perhaps, is the form of sluice adopted in the Fourneyron turbine, a circular cylinder which slides in the clearance-space. It is obvious that, when the stream entering the wheel is narrower than the width of the wheel, there must be a general breaking-up of the stream, and a complete alteration of the conditions of pressure and velocity for which the wheel-curves are designed.

The curves for the Hercules and Humphrey turbine show results, I believe, as good as any reliable results obtained in America, the latter being perhaps the most reliable, because the experiment was made by Mr. Francis, whose experience in measuring water by weirs is probably greater than that of any other engineer.

The sluice-arrangements in American turbines do not seem, from the theoretical point of view, particularly good; but although American makers do not explain the principles on which they proceed, I suspect that in these turbines some approach is made towards the condition of free deviation, in which case the defects of the sluice produce a less unfavourable effect.

For pressure-turbines only one approximately perfect mode of regulation has ever been adopted, and that is the movable guide-blades of Professor James Thomson. With this arrangement the water enters the wheel over its whole circumference and depth, with its velocity and direction little changed, in all positions of the guide-blades. The only objection to this mode of regulation is that it involves a certain amount of mechanical complication.

For Girard turbines with partial admission, the mode of regulation is simple, and perfectly complies with theoretical conditions; the width of the stream entering the wheel is altered without in any way affecting the perfect action of the water in the wheel.

On Prince Bismarck's estate at Varzin, three considerable factories worked by turbines have been erected. In the first, in which considerations of capital expenditure were the ruling ones, the turbines were guaranteed to give only 60 per cent.; in the second, 70 per cent.; and in the third, to which I am now referring, the turbines were guaranteed by the makers to give 75 per cent. with full sluice and 70 per cent. with half sluice. If this guarantee

was not satisfied, the turbines were to be removed without recompense by the makers. These turbines are Girard turbines; and to ascertain whether the conditions of the contract were satisfied, an extremely careful series of experiments were made, the supervision of which was confided to Professor Zeuner, one of the most distinguished professors of mechanical science in Europe. There are two turbines, each of about 200 HP., on about 12 feet fall. The general result of the experiments was that the efficiency of the turbines was 0·795 with full sluice, and 0·801 with the sluices half-closed, and with the same turbine speed in both cases. These results are the means of four trials in each case, which varied extremely little from one another.

The most careful estimate of the separate losses of work in a turbine which I have met with, is that made by Mr. Lehmann. He has analysed experiments on thirty-six turbines, varying from 1 to 500 HP., and has estimated the average losses of energy from various causes as follows:—

| Loss per cent. due to . . . . . | Axial Flow. Turbine. | Outward Flow. Turbine. | Inward Flow. Turbine. |
|---|---|---|---|
| Hydraulic resistances . . . . | 12 | 14 | 10 |
| Unutilized energy. . . . . . | 3 | 7 | 6 |
| Shaft friction . . . . . . . . | 3 | 2 | 2 |
| Total . . . . . . . . | 18 | 23 | 18 |
| Efficiency . . . . . . . | 0·82 | 0·77 | 0·82 |

I shall be told—especially by users of turbines in this country—that there are numerous cases of failures of turbines; of turbines which are not giving satisfaction, or which, if they are doing their work, are using an extravagantly large amount of water. There is, no doubt, ground for these complaints; but the reason is not far to seek. Turbines are too often built by manufacturers without adequate hydraulic knowledge. The continued construction of turbines with thoroughly bad systems of regulation is a proof of the want of such knowledge. But most often the turbine fails from quite another cause. No adequate preliminary inquiry is made as to the local conditions in which a turbine is to be placed. Some previously manufactured size of turbine is selected, and put in with very little regard to the precise conditions in which it is to work. The variations of the fall, and the variations of the water-supply, are neither of them determined. Naturally it results that the proportions of the turbine are unsuitable, and the turbine is blamed instead of its constructors.

*American Turbines.*—There is an opinion in some quarters that the best turbines are now American turbines. I should be sorry to underrate the value of American experience in turbine-building, but on one point I can speak confidently. There is nothing new in principle in any American turbine. The Americans adopted in turn the Fourneyron, the Jonval, the inward-flow, and the mixed-flow turbines, and, so far as I can see, they have copied, without any material change, the turbines of Europe. There are amongst American turbines some so mal-constructed that they look as if they had come from the region behind the looking-glass. Others, no doubt, are excellent; but where they are best they most nearly approach ordinary European patterns. Many American turbines are mixed-flow turbines. This type of turbine is probably the cheapest to construct of all the pressure-turbines, and, like the inward-flow, permits a good mode of regulation. But there is absolutely no advantage in the efficiency to be got by twisting the water round a vane of double curvature, over that which can be got with a vane of simple curvature. In their purely practical aspect, the best American turbines are excellent. They are well manufactured, and attention is paid to designing them so that they can be cheaply erected.

*Steam Turbines.*—Steam under pressure will work a turbine as well as water under pressure, and with no great alteration in the methods, a steam turbine can be designed like a water turbine. But there is a practical difficulty in the way of the adoption of steam turbines not yet overcome. For steam of, say, 30 lbs. pressure, the height corresponding to the pressure is about 60,000 feet. The velocity due to the head is such that the circumferential speed of the turbine must be about 1,000 feet per second. So soon as we can find a material strong enough and durable enough to stand an excessive speed of that kind, so soon we may have steam turbines much smaller and cheaper, and not less efficient than ordinary steam-engines.[1]

Sir FREDERICK BRAMWELL, President, was quite sure the members had been instructed by the lecture which had been delivered by Professor Unwin. He had dealt with a subject of very great

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The account of the Pelton wheel is from a Paper by Mr. Hamilton Smith in the Proc. Am. Soc. Eng. The Author has to thank Mr. Ellington for drawings of the Hastie engine, and Mr. Gunther of Oldham, Mr. Gilkes of Kendal, Mr. Hett of Brigg, and Mr. A. Rigg, for drawings of turbines exhibited at the lecture.—W. C. U.

importance and of considerable intricacy in a manner which had made it clearer to them than a great deal of study under other circumstances would have done. He had therefore great pleasure in proposing a hearty vote of thanks to the lecturer.

Mr. Woods, Vice-President, said he need not add anything to the remarks of the President in reference to this most interesting lecture, and he would accordingly content himself with seconding very heartily the vote of thanks that had been proposed.

The vote of thanks was unanimously agreed to.

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[Appendix.

Canals in general.

The history of canals from the time of Alexander, the Ptolemies, and Marius, down to the days of Riquet, Brindley, Smeaton, Telford, Rennie, and De Lesseps, is published in countless volumes accessible to every one. I need not therefore follow in the old track, and try to vary the recitals by conjectures concerning the priority of invention, by the Italians or Dutch in the fifteenth century, of the lock, by which alone inland navigation eventually became generally applicable and useful; nor need I dwell on the fact that at home and abroad, during the latter half of the eighteenth century, there was as great a rage for canals as in the second quarter of this century for railroads.

Inter-oceanic Ship Canals.

I should not omit, however, to notice the circumstance that, great as has been the check by the introduction of railways to the construction of canals for the use of barges, the latter part of the present century will ever be famous for its great isthmian ship canals, such as the so-called artificial Bosphorus at Suez, which has already diverted the old lines of commerce in a remarkable manner, and the Panama Canal, which is apparently destined to effect a still more notable revolution in the old trade routes, before the end, let us hope, of the present decade.

Tidal ports.

But as the theme allotted to me is inland navigation, I must perforce be silent on the topic of inter-oceanic waterways; and the same restriction applies to tidal ports and tidal rivers—a subject which is in the programme of a lecture to be delivered next month from this platform by a very distinguished member of this Institution, Mr. Thomas Stevenson, of Edinburgh.

Theories.

As to the theoretical part of my subject, I have no new theories to propound, or old ones dressed up in a new garb, to place before you; but in saying this, I desire to indicate to any student in hydraulics who may be present to-night the best sources of information with which I am acquainted concerning the most generally accepted theories in this country, and the most recent experiments of value on the flow of water, namely, Dr. Robison's remarkable article under the head of "Rivers" in the last completed edition of the "Encyclopædia Britannica," and to the experiments of Major Cunningham,[1] R.E., on the Ganges canal.

## Inland Navigation in Great Britain and Ireland.

British Rivers.

The lower parts of the chief rivers of the United Kingdom are mostly arms of the sea, navigable at high water by ships of the

[1] Minutes of Proceedings Inst. C.E. vol. xxi. p. 1.

largest burden. Higher up stream, where the tidal influence is gradually diminished, they are generally navigable for ordinary river steamers, and, finally, when the tide is no longer of any avail they are in many cases canalized for the use of barges up to points which appear to be best adapted for the departure of entirely new waterways to navigable channels in other river basins.

The Thames.

As a case in point, the Thames (218 miles in length) is navigable for the largest vessels from the Nore to London Bridge (48 miles), and thence for ordinary steamers to Teddington (20 miles), where the canalized portion of the river begins, and whence it is navigable as far as Lechlade, situated at 24 miles below Thames head. The total fall between the latter and London Bridge (170 miles) is 250 feet. Again, the Thames, at certain parts of its course above London Bridge, is united by means of a grand network of canals with the Solent, the Severn, the Mersey, the Humber, and the Trent; and thus, independently of its estuary, the Thames is in direct inland communication not only with the English and Irish Channels and the North Sea, but with every inland town of importance south of the Tees. With reference to the estuary of the Thames, trustworthy evidence was taken before arbitrators in 1879–80, in a case concerning the navigable condition of the Thames, by which it appeared (1) that of the entire area of its basin, 5,162 square miles, 3,676 belonged to the non-tidal area, and 1,486 to the tidal portion below Teddington; (2) that the mean volume discharged from the tideless portion was 1,540 cubic feet per second over a period of twenty-five years ending 1878, or about 2,000 cubic feet per second at Crossness, 13 miles below London Bridge, from a total area of 4,661 square miles; and (3) that at Crossness the proportion of inland water (when the river is running moderately full) to tidal water (at an ordinary spring tide) is 1 in 26.

These figures are given with a view to enable comparisons to be made between our famous English river, on which is situated the chief commercial port and city in the world, and certain rivers on the Continent, shortly to come under review, of incomparably greater magnitude, but nevertheless of infinitely less importance as great highways of trade.

British Canals.

The absolute length of inland navigations in the British Isles seems to be rather a difficult matter to arrive at with exactitude, for whilst Mr. Calcraft of the Board of Trade states it to be 2,688 miles in England and Wales, 256 in Ireland, and 85 in Scotland, or 3,029 miles in all, exclusive of the rivers Thames, Severn, Wye, Humber, Wear, and Tyne in England, the Shannon and other

navigations in Ireland, and the Clyde, Forth, and Tay in Scotland, Mr. Conder, M. Inst. C.E., who has for many years past given special attention to railway construction and the cost of transport generally, estimates the length of inland waterways at 4,332 miles in England and Wales (of which 2,919 are canals and canalized rivers, and 1,413 navigable rivers), 755 in Ireland, and 354 in Scotland, or a total of 5,442 miles. As to the cost of construction, the same authority has obligingly informed me that according to his researches the total cost of the canals and canalized rivers in England and Wales (4,332 miles) was £19,145,866, giving an average of £6,052 per mile, the minimum (Fen water canals, 431 miles) costing £4000 per mile, and the maximum (Thames and Humber river and canal systems, 393 miles) £10,000 per mile, including the Regent's canal, which cost £120,000 per mile.[1] The carrying power of barges on British canals varies, with but few exceptions, from 20 to 80 tons when loaded down to draughts of from 3½ to 5 feet. The average dimensions of the locks, by which of course the size of the barges is regulated, are 80 feet by 14 feet, not taking into account of course the exceptional cases of the Weaver navigation (the best study in England at present of modern canal appliances), the new Aire and Calder canal, and the Gloucester and Berkley canal. There is a lock on English canals at every 1⅓ mile on an average, and the loss of time they occasion to barges is estimated at about two minutes per mile. Taking this retardation into account, the mean speed of barges in England by horse traction may be stated at 2½ miles per hour.

According to Mr. Conder, the working expenses of steam lighters on the Forth and Clyde canal (35 miles long, and accommodating vessels of 8½ feet draught) are 0·23*d.* per ton per mile, including all expenses, but excluding interest on works; the average working expenses on all the English waterways are 0·26*d.* per ton per mile, or 0·37*d.* including 4¼ per cent. interest on capital, and the cost on the Thames 0·10*d.*, as compared with 0·083*d.* per ton per mile on the Aire and Calder Canal, for steam-tug expenses only.

There are no examples in the United Kingdom of cable-towing. A costly experiment of the system was tried on the Bridgewater navigation some years ago, but it was not adopted there, as the distances between the locks are short and the navigation tortuous.

Caledonian Canal.

No account, however short, of British waterways should omit

[1] The total length of railways open for traffic in the United Kingdom on the 1st January, 1884, was 18,681 miles, and the total capital paid up thereon £784,921,000, giving an average of £42,000 per mile.

to mention Telford's masterpiece, the Caledonian Canal. This celebrated work has a length of 60½ miles, of which 37½ are natural lake navigation, and 23 are artificial or canal navigation. The standard depth of the canal is 18 feet, giving access to vessels 160 feet in length, 38 feet beam, and 17 feet draught. The summit level is 102 feet above the sea, and at Corpach, its southern extremity, eight locks are clustered together up the side of a hill, to overcome a height of 64 feet. The cost of the canal was about £1,000,000 sterling.

### Inland Navigations on the Continent of Europe.

It is a far cry from England to Russia, but as this lecture is meant to embrace inland navigations generally throughout Europe, a succession of long and sudden leaps is unavoidable in a voyage covering so much ground. Hence my excuse for hurrying on without further preamble to the most northerly country of the Continent, with the intention of then working west about to Roumania, which marches with her gigantic neighbour along mid-channel of the lower Pruth to its mouth near Reni, and thence by the left bank of the Danube and the new frontier line of the Kilia mouths to the Black Sea.

### Russia in Europe.

European Russia is forty times larger than England, having in round numbers a length of 1,600 miles from the confines of Scandinavia, Germany, and Austria, a width of 1,300 miles from the Arctic Ocean to the Black Sea, and a total area of 2,000,000 square miles, or more than one-half that of Europe.

With the exception of the little group of the Valdai Hills the main divisions of European Russia are the frozen "tundras" of the Arctic coast, the rock and lake plateau of Finland, the great forest and corn-bearing lands of the central region, and the vast treeless "steppes" or pastoral lands of the south and south-west, the chief characteristic of the whole landscape being that of an apparently illimitable gently-rolling plain, without a hill in view to break the monotony of the horizon. Thanks, however, to its comparatively low elevation this enormous region enjoys a river and lake system of navigation on an immense scale, and in order to complete Nature's handiwork—for hitherto Russian rivers have been little improved by the hand of man—a well-considered system of artificial canals has been established, by means of which the whole country can readily be traversed by water from end to end. European Russia possesses 19,000 miles of navigable waterway, and 38,000 miles of raft-bearing rivers. In summer these great high-

ways transport raw products to the south and west, and receive back manufactured goods, whilst in the long winter months, from October to May in the north, and from November to April in the south, all inland traffic is necessarily carried on either by means of railways, of which there is already a length of 16,000 miles in European Russia, or by sledges over the frozen ground in districts where railways are still unmade or temporarily buried in snow.

The chief inland waterways of European Russia will now be briefly passed in review, after drawing attention to the fact that the great watershed of Europe—that which separates its northern from its southern drainage—coincides throughout the eastern half of the continent with a low range of hills, which in their greatest elevation, the Valdai plateau, hardly reach more than 1,100 feet, and which widens out in some parts into an expanse of marsh.

Thus to the north of this watershed the Petchora flows into the Arctic Ocean and the Dwina into the White Sea: to the north-west the Neva and the Duna fall into the Baltic; to the south-east the Ural and Volga fall into the Caspian Sea; and to the south, the Don, the Dnieper, the Bug and Dniester fall into the Black Sea.

Petchora.

The Petchora, 915 miles in length,[1] with a drainage area of 127,000 miles, has but 10 feet of water on its bar, and is only free from ice during a third of the year. Nevertheless, its traffic in cereals and raw produce in the short summer season is very considerable.

Dwina.

The Dwina has a course of 650 miles, and becomes navigable on receiving the Vichegda, where it turns to the north; but though at the Port of Archangel the water is very deep, it is only accessible to vessels of a less draught than 14 feet—the maximum depth over the deepest of the four mouths of the river which empty themselves into the gulf of the Dwina, about 30 miles below Archangel.

Ural.

The Ural has a course of 1,446 miles, and drains an area of 95,000 square miles, but the volume of its waters does not correspond with its length and the extent of its basin as compared with rivers in moister climates. It is navigable for small craft for most of its length, and enters the Caspian by three mouths of great width but insignificant depth.

Volga.

The Volga, the longest river in Europe, and the chief commercial road of the whole Russian empire, rises in the Valdai Hills, at an elevation of 663 feet above the Caspian Sea, into which it flows

[1] The areas of the drainage basins of Russia and Germany are mostly after Strelbitsky. All measurements are in English statute miles of 5,280 feet.

through upwards of seventy mouths, after a tortuous course of more than 2,000 miles. Its drainage area is 563,000 square miles. With its tributaries, it affords 7,200 miles of navigation, and is connected by canals with the White and Black seas, the Baltic, and the Azov. The Volga first becomes navigable for small steamers at Tver, whence it flows almost due east to its confluence with the river Oka (which drains 93,000 square miles) at Nijni Novgorod, so celebrated for its great fairs, and then on in the same direction to the large manufacturing and semi-Asiatic town of Kazan. Hence to the Caspian Sea there are said to be only four towns on the left bank of the river, as against more than thirty on the right; and this is readily accounted for by the fact that it is chiefly the left bank that is liable to be flooded, the right bank being mostly the higher and steeper of the two—a remark, it may be said in passing, that also applies to the Dnieper, the Don, and the lower Danube. About 50 miles below Kazan and 300 below Nijni Novgorod, the Volga receives the waters of its chief feeder, the river Kama, which rises in the Ural mountains, and drains 200,000 square miles. As upwards of 900 miles of its total length of 980 are navigable, and as it is the great artery of communication with Siberia, the traffic of the Kama is very important. From its confluence with the Volga to Astrakhan, the great river flows nearly south for 1,200 miles, and, owing to the dryness of the climate, receives no other tributary of importance in the remainder of its course to the sea. In this distance it spreads out in many places to a width of several thousand feet, with depths varying from 3 feet at dry seasons, where the width is abnormal, to 50 feet and upwards in the concavities of sharp bends and in narrow places.

Hitherto no permanent works have been undertaken to improve the navigation of the Volga, and the Russian Government will hesitate a long time yet, I think, before rushing into heavy works for that purpose, for not only would they be exceedingly costly, but their effect would be very uncertain. Meanwhile, in the lower part of the river, the removal of shoals which are formed annually by the spring floods is effected by dredging, by provisional lattice groynes, and, during the last three or four years, by what is called a new system of iron harrows,[1] which are said to have doubled the navigable depth over certain shoals in a few days, and, in one instance, at the Chebocksarsk shoal where the depth was only 2 feet 4 inches right across the river, to

[1] Minutes of Proceedings Inst. C.E. vol. lxxvi. p. 393.

have deepened the water 3 feet in six days, over a sufficiently wide channel, and to have given a depth therein of 2 metres in a fortnight. This reference to shallow water in the Volga will give an idea of the difficulties the navigation has to contend with at certain seasons of the year; nevertheless upwards of six hundred steamers navigate the river and its chief tributaries, and trade goes on increasing rapidly.

Six days are generally needed to steam down from Nijni Novgorod to Astrakhan. Stoppages, both up and down stream, are always made at Tsaritzyn, on the right bank, which is connected by rail with Kalatch, on the left bank of the Don. The distance between the Volga and the Don, at Tsaritzyn, is only 49 miles, but as yet the only water communication between these two great streams is by means of the Upa canal, which connects the Oka with one of the upper reaches of the Don, thus uniting the Caspian Sea with the Azov.

The flourishing town of Astrakhan is situated on the right bank of the Volga, at a few miles above the head of the delta, 1,440 miles below Nijni-Novgorod, 320 below Tsaritzyn, and 50 from the Caspian Sea. Although the Volga is longer than the Danube, and the area of its catchment basin 90 per cent. greater, the volume discharged by the Volga is less than two-thirds of that discharged by the Danube, a circumstance which is explained by the fact that in the region traversed by the former there is relatively a much smaller rainfall than in the most westerly parts of Europe.

At the numerous mouths of the Volga, which frequently change in direction and volume, the south, or principal one, is happily kept open for the passage of small steamers by the action of the prevailing S.S.W. winds, which tend to drive the detritus northwards, and thus partially to choke up the subsidiary channels to the north-east.

The Caspian Sea.

This inland sea has an area of 160,000 square miles, and the level of its surface is 84 feet below that of the Black Sea. Its trade is now very important, owing principally to the great increase of late years in the production of petroleum from wells sunk near that ancient seat of fire-worship, the Port of Baku. In 1883 the transport by rail and steamer of this industry alone amounted to 206,000 tons, of which more than one-half was produced by the enterprising Swedish firm of Nobel Brothers. A large fleet of cistern steamers are already employed in connection with this trade, and it will be interesting to engineers to watch the effect on the water traffic when the means now in progress to facilitate the land transport by rail and lines of iron tubing have

been perfected. By this combined system of carriage it is anticipated that ultimately there will be no difficulty in exporting the 250,000,000 gallons a year which experts assert can regularly be obtained from the Caucasian regions, a supply, it may be added, which is equal to the present wants of the whole world. Apropos of this interesting question of the petroleum trade it may not be out of place to quote a passage from a letter I received last month from H.B.M.'s Vice-Consul at Odessa. He says: "We have in port a small light-draught screw steamer—150 tons burden dead weight—called the 'Samuel Owen,' which has just arrived from Baku (Caspian Sea) *viâ* the Volga, the Marie system of canals, Lake Onega, River Neva, and thence round Europe to Odessa." Now as the distance, by land, in a straight line from Baku to Odessa is less than 1,000 miles, and as the distance steamed over by the "Samuel Owen" must have been fully 8,000 miles, it appears to me that the voyage of this vessel is a remarkable illustration of the preference that is given, in certain cases, to water over land transport, even when the former mode of transit involves the delay attending an extraordinarily circuitous navigation by lakes, rivers, canals, and narrow seas, to attain the end in view.

The Don rises in the Ivan lake, 586 feet above the sea; its length is 980 miles, and its drainage area 170,000 square miles. This river is navigable for large rafts of timber down to the mouth of its first great tributary, the Voronjo, at Tavrovsky, on the left bank (where Peter the Great built his ships of war for the Black Sea), and thence to Kalatch it is navigated by small steamers. From Kalatch, which, as we have seen, approaches within 49 miles of the Volga, large freight steamers start several times a week for Rostov, the largest commercial town in Russia after Odessa, and situated on the right bank of the river at the head of the delta. The quantity of merchandise floated down, including the traffic of the Donetz, which enters the Don between Kalatch and Rostov, as well as that of the Sosna, another tributary which enters it between Voronej and Kalatch, is above 200,000 tons annually, exclusive of large deliveries of anthracite coal, which is obtained from Novo Tcherkask and Lugan (about 100 miles above Rostov), and sent down the Don for the use of the Russian steamers in the Azov. Don.

A short distance below Rostov, where, according to my own observations, the sectional area of the river at low water is 23,300 square feet, the Don splits up into two channels (Plate 3) which ultimately give birth to five separate mouths, at the deepest of which, the Perevoloka mouth, 25 miles below Rostov and 15 miles from the Taganrog roadstead, the available depth is rarely more than 6 feet.

During the summer of 1882, and in November, 1884, however, all the bars of the Don were completely dry for several hours, owing to the effect produced by a long-continued east wind. On the other hand, in 1866 (when the mouths of the river were surveyed under my direction), a long series of hydrographic observations recorded the interesting fact that after a long and stiff blow from the W.S.W., and therefore from seaward, the water at the Perevoloka mouth rose 9 feet above its ordinary level, thus giving a momentary depth of 15 feet on the bar, and so causing the current to flow upstream past Rostov with considerable velocity.

After this description of the mouths of the Don, it need not be said that the river is only accessible to coasters of light draught. Sea-going vessels either take in their cargoes from lighters in the Straits of Kertch, where there is now a depth of 15 feet, or in the roadstead of Taganrog, which, on account of shallow water, is 10 miles distant from the port of Taganrog. Taganrog is one of the three privileged ports of the Empire for the importation of foreign goods, and the great entrepôt for the commerce of the Volga and the Don.

Dnieper. The Dnieper drains an area of 204,000 square miles, and rises not far from the source of the Volga. In its length of 1,060 miles it flows nearly south from Smolensk to Kiev, below which its direction south-east to Ekaterinoslav, and thence south and south-west to the Black Sea. Its first great tributary below Smolensk is the river Berezina (which is joined to a branch of the river Duna by the Berezina Canal); but its most important feeder is the Pripet, which joins the Dnieper at about 60 miles above the city of Kiev, the "Jerusalem" of Russia. The Pripet is 380 miles in length, and rises within a few miles of the right bank of the northern Bug, which flows into the Vistula. By the Oginsky Canal the Pripet is connected with a branch of the river Niemen, and thus there is an alternative means of inland water-communication between the Black Sea and the Baltic. The Desna, the third tributary of importance, joins the Dnieper on its left bank at Kiev, and contributes a large quota of trade to the main river in the early summer when it is navigable as far as Briansk in the province of Orel. At Kiev, where, as we all know, the Dnieper is spanned by Vignoles's magnificent suspension bridge, the river is 1,500 feet wide, but thence to Krementchug, about 100 miles above Ekaterinoslav, it occasionally exceeds 1 mile in width. The minimum depth between Kiev and Ekaterinoslav is 3 feet. At Krementchug a large trade is carried on in tallow, salt, grain, and beet-root sugar, and large storehouses are provided for the half-manufactured produce brought down the Dnieper and

its tributaries from the provinces through which they flow, as well as for goods brought overland from the interior.

Steamers ply daily in summer between Kiev and Krementchug, and every other day between the latter and Ekaterinoslav, an important town on the right bank, about 60 miles above Alexandrovsk, a large port on the left bank at the foot of the cataracts of the Dnieper. This great obstruction to the navigation, which I inspected in 1873 at the request of the Russian Black Sea Steam Navigation Company, is caused by a granite outshoot of the Carpathians, and consists of nine distinct rapids in a length of 47 miles, the total fall being 107 feet. The most formidable of these obstacles are the Koidatsky, Nenasitetsky, the insatiable (Plate 3), and Volingsky Rapids, their average length being only 7,700 feet, with a total fall of 34 feet. Several abortive attempts were made between 1788 and 1833 to improve the navigation by means of side-cuttings near the shore line, but no improvement of any kind was effected till 1853, when, after ten years' work, a series of canals were formed in the bed of the river, and protected at the sides by parallel walls of rock-work, furnished with splayed guiding-walls facing up-stream, with the view of allowing vessels of small draught to make use of them at certain seasons of the year, when the rapids would otherwise be impassable. In practice, however, their only use has been to allow of the occasional passage of undecked flat-bottomed barges carrying from 5 to 7 tons, and drawing 18 inches at extreme low water. At all other seasons the confined artificial channels, which have a width of about 140 feet, are regarded as mere traps at each one of the rapids, and are therefore always carefully avoided by descending vessels. No cargo-boats ever ascend the rapids, and the whole trade over them is consequently limited to rafts of timber and to raw and also manufactured produce floated down-stream from long distances in lightly-constructed barges, which are broken up and the wood used for building purposes on their arrival at Kherson, a languishing port on the right bank at the head of the Delta, 216 miles below Alexandrovsk.

Immediately after passing Kherson, the Dnieper divides into several channels, and finally delivers its waters into the Bay of Kherson by nine mouths, at the deepest of which, by the aid of occasional dredging, a depth of 10 feet is generally maintained.

In spring, when barges drawing from 5 to 6 feet can descend the river from the foot of the rapids to Kherson, there are barges carrying 100,000 tons plying between Alexandrovsk and Odessa, a distance of 306 miles, at an average freight of 7*s.* per ton. At

the low-water season, however, the rates sometimes rise to 15*s.* per ton.

Bug. The Southern Bug rises in Podolia, and after a course of 430 miles enters the Bay of Kherson at 30 miles west of the town of Kherson. It drains 26,000 square miles, and can be navigated by craft drawing 6 feet for about 80 miles above the town of Nikolaev, which stands on the east bank of the river at 20 miles from its mouth, and at the junction of the rivers Ingul and Bug. Nicolaev is the Russian arsenal of the Black Sea, and ships-of-war are built and launched here, and pass into the Bug from the Ingul by a channel 20 feet deep, a depth which diminishes to 17 feet at the entrance of Kherson Bay, off Kinburn. The tonnage of vessels cleared from the port of Nicolaev with cargoes of grain in 1882 was 162,000, a shipment which is much below the general average.

Dniester The Dniester rises in the Carpathian Mountains in Galicia, and flows south-east into Russia. It forms the boundary between Bessarabia on the right, and Podolia and Kherson on the left, and its waters, after passing through a wide and shallow estuary below Akerman, enter the Black Sea on a low sandy shore between Odessa and the Danube mouths. Its total length is 640 miles, and, like the Bug, having no tributaries of importance, it only drains 30,000 square miles. Its channel is broken up by rapids near Bender, and below that historic town is only navigable for vessels drawing less than 8 feet, whilst at its principal mouths the depth varies from 4 to 6 feet.

A long leap backwards must now be made to the north of Russia, to carry out my programme to work west about from the North Sea to the Danube mouths.

The Baltic Sea. The Baltic has been well termed an estuary rather than a sea, receiving as it does a number of rivers, none of them individually of great size, but collectively draining an area equal to one-fifth of the entire area of Europe. Near the mouths of these rivers, the depth of water becomes greatly diminished, and, like the Black and Caspian Seas, there being little or no tide, and the water being comparatively fresh, the surface of the Baltic, which is emphatically a shallow sea, soon becomes frozen. Hence all its ports are sealed up for more than a third of the year, and during this long period the inland navigation of north-eastern Europe is entirely suspended.

Neva. The Neva is only 34 miles long, and its waters are immediately derived from Lake Ladoga, which, having a surface of 7,000 square miles, is the largest fresh-water lake in Europe. The Ladoga receives the contributions of numerous other lakes, including Lake Onega, which covers an area of 3,800 miles, or seventeen

times that of the Lake of Geneva. The entire area drained by the Neva is 112,000 square miles, and through Lake Onega it is connected with the Dwina and the Volga by canals, through which small vessels can pass from the Baltic into either the White Sea or the Caspian.

St. Petersburg Canal.

Before taking leave of the Neva, a few words should be said regarding the new canal, which now unites the commercial harbour of St. Petersburg and the military port of Cronstadt. When I journeyed between these two places on the ice in mid-channel in the upper part of the Gulf of Finland, in 1869, the carrying trade through the Baltic, to and from St. Petersburg, had to be done almost entirely by transhipment at Cronstadt, as at that time lighters only could cross the 8 to 9 feet of water at the long bar of the Neva. The construction of a maritime canal to unite St. Petersburg and Cronstadt, designed originally by Peter the Great in 1725, was only begun in 1878, and thrown open to commerce in October last. This canal is 18 miles in length, with a floor width of 276 feet, and an actual depth of 20 feet. This depth is now being increased to 22 feet at ordinary low water. With regard to this level, it is worthy of notice that, during the construction of the works, strong winds from seaward raised the level of the gulf 9 feet on one occasion, whilst on another a strong N.E. wind lowered the water 5 feet; the extreme difference being 14 feet, as compared with 15 feet from the same causes at the mouths of the Don.

The estimated cost of the St. Petersburg Canal is 10,000,000 roubles, a sum well spent, in my opinion, on such a work, although, notwithstanding its obvious utility, both from a commercial and strategical point of view, there are many self-dubbed authorities, especially among those interested in the lightering trade, who maintain, as invariably happens in similar cases, that the canalization will turn out anything but a success in practice.

Duna.

The Duna rises near the source of the Volga, and drains an area of 33,000 square miles. Its length is 470 miles, and its general direction north-west. It forms the frontier between Livonia and Courland, and enters the Gulf of Riga 7 miles below the town of Riga. The navigation of the river is obstructed by rocks and sandbanks, but during the floods of spring and autumn its products are readily transported in barges to the Baltic. The depth of the navigable channel at Riga is 17 feet, but at the entrance to the Duna, at the head of the north pier, 9 miles below Riga, the depth in 1881 was only 14 feet.

Canals.

The total length of the canals in European Russia is about 200

miles. In most instances they have been formed with but little difficulty across the gentle undulations of the great watershed, thus uniting, as we have seen, the head-waters of rivers which have their outlets at opposite extremities of the continent.

## SWEDEN.

Sweden abounds in lakes, which cover more than 14,000 square miles of its surface. Of these the Wenern and the Wettern are the largest, the former having an area of 2,400 square miles, and the latter 760. The Mälar Lake, with its one thousand three hundred beautiful islands of all sizes, is also of great extent. None of the rivers are navigable, excepting those which have been made so artificially, and nearly all are obstructed by cataracts and rapids. Nevertheless Sweden has remarkable facilities for internal navigation, during the seven months that the country is free from ice, by means of a series of lakes, rivers, and bays, connected by more than 300 miles of canals. These furnish direct water-communication between the Baltic and Gothenburg, the chief commercial town of Sweden, situated upon the estuary of the Gotha river, 5 miles from the Cattegat. Plans for effecting this communication were devised long before they were carried out. In 1800 the Trollhattan or Gotha canal, at the head of the river Gotha, where it descends 108 feet in 5 miles, was opened to the navigation, and improved and widened to the dimensions of the Gotha canal between 1836 and 1844. This celebrated canal, which I visited in 1880, was founded at the beginning of this century by Count Von Platen, the De Lesseps of his day. In 1808, he summoned to his aid Mr. Telford, the first President of this Institution, who, after visiting the ground, prepared and sent in a series of detailed plans and sections, with an elaborate report on the subject. His plans were accepted, and the works were begun in the following year, but although the West Gotha canal was opened for traffic in 1822, the two Swedish seas were not connected before 1832. Of the entire distance of 370 miles between Stockholm and Gothenburg, only about 50 are canal, and the same distance along the coast of the Baltic, the remaining 270 being through lakes, bays, and rivers. The canal is now everywhere 48 feet wide at the bottom, 90 at the surface, and 10 feet deep. In 1855 it was thrown open to steamers. Its most elevated point is Lake Wiken, between Wettern and Wenern, where it is 300 feet above the level of the sea. The descent is made by vessels through thirty-seven locks, or seventy-four from sea to sea; and as several of the lock chambers, which

Gotha Canal.

are 120 feet long and 24 broad, are grouped together where the ground is steep, vessels have the appearance every here and there of slowly descending a flight of gigantic stairs.

The total length of the railways in Sweden and Norway is 3,937 miles, of which one-third belongs to the State.

## Germany.

The German empire owns parts of seven river valleys, and three large coast streams. Of the latter, the Pregel flows to the Baltic, and the Eider and Ems to the North Sea; of the former, the Niemen (or Memel in German), Vistula, and Oder, flow to the Baltic; the Elbe, Weser, and Rhine, to the North Sea, and the Danube to the Black Sea. Of these seven large rivers, the Weser is the only one which belongs entirely to the German empire; of the Elbe and Oder the larger part; of the Rhine the larger half; but of the Danube only one-fifth part. The hydrography of all these rivers, with the exception of the Danube, will now be briefly described.

The drainage area of the Niemen (35,000 square miles) is conterminous with that of the Duna, and of about the same extent. The Niemen rises in Russia, becomes navigable at Grodno, and divides at Winge into the Russ and the Gilge, both of which fall into the Kurisches-Haff, one of those peculiar lagoons characteristic of the shores of the Baltic opposite their river mouths. The Niemen enters the sea at the port of Memel, the central point of the timber trade of the Baltic. The depth of its harbour is 23 feet; but on the bar of the river, 2 miles below the town, the depth is 18 feet only. By means of an artificial canal between the Upper Niemen and the Pripet, already described, vessels can pass from Memel to the Black Sea. The Niemen.

The Vistula rises in Austrian Silesia in the Carpathian mountains at 2,000 feet above the level of the sea, and its basin drains 74,000 square miles, including the whole area of Russian and Prussian Poland. In its length of 600 miles, it flows past Kracow and Warsaw, becomes navigable for vessels of from 7 feet to 8 feet draught at ordinary high-water level at the German frontier, and carries this depth to its principal mouth at Plonsdorf, about 5 miles east of Dantzig (Plate 3), the chief port of Germany in the Baltic. Vistula.

Dantzig is situated on the west, or left bank, of an old arm of the Vistula, through which the current ceased to flow on the 31st of January, 1840, when, owing to the effect of a sudden break

up of the ice, the river formed for itself a new mouth at Frondorf, nine miles below the old mouth at Neufahrwasser, which is now completely closed. In the following year a lock, with 10 feet of water on its sill, was built across the old arm close to the new entrance, to ensure the easy passage of river craft between Dantzig and the interior of the country, and in 1846 the old lock at Neufahrwasser, constructed in 1801–1805, being no longer needed, was destroyed, and a wide open channel substituted in its place.

From Dantzig to Neufahrwasser, a distance of 5 miles, and thence to deep water at the head of the east pier, the dredging of a channel 200 feet wide and 23 feet deep is now on the eve of completion.

In 1848, the navigation of the Vistula between the new mouth and the head of the delta, where the river bifurcates into the Nogat, or east arm of the river, and the Dantzig, or west arm, became so difficult that works of correction were begun in that year by the Prussian Government to ensure a regular flow of water through both branches, and, as it was hoped, to improve their navigable condition as well. In 1858, a short time after the works were completed, I visited the ground and obtained, through the kindness of the Government engineers, certain technical information of interest, which I venture to reproduce in this place, as it refers to a very delicate operation in river engineering, namely, that of radically changing with success the relative flow of two branches of a great river at a point where they separate from their parent stem never to reunite. In the Vistula, immediately above the head of the delta, the volume discharged at zero or extreme low water is estimated at 8,766 cubic feet per second, and at high water, when its level stands at 10½ feet above zero, at 76,700 cubic feet per second. Of this quantity, three hundred years ago, two-thirds passed by the Dantzig branch, and one-third by the Nogat. The latter, however, having a steeper slope than its sister branch, went on gradually increasing in volume, until, in 1840, the proportions were completely reversed, and it appeared highly probable that unless the art of the engineer stepped in before long to re-establish the old order of things and to fix the flow at the bifurcation, the Dantzig branch would silt up altogether. Hence the contemplated works had principally in view the restoration of the old regimen, by means of which the Nogat, instead of withdrawing two-thirds of the total volume of the main river, should have its flow permanently brought back to the original proportion of one-third only.

The works were admirably executed, and principally consisted of the cutting of an entirely new channel (Plate 3), furnished with

incorrodible sills and revetments for the waters of the Nogat; the blocking up of its old channel by several substantial dams; the construction of extensive training works from the fork down to Dirchau on the one branch, and Marienburg on the other; and the construction of twenty-six massive ice-breakers across the new Nogat entrance.

The result of the works (the cost of which is estimated at £600,000) has proved:—1st. That the discharge of the Nogat as compared with that of the undivided Vistula, is now only 10 per cent. at low water, 24 per cent. at ordinary water-level, and 28 per cent. at high water, and consequently the discharge of the Dantzig branch 90 per cent., 76 per cent., and 72 per cent. respectively of the total flow at the same periods. 2nd. That a good navigable channel everywhere 8 feet deep is now available in the Dantzig branch, whilst at low water in the sadly impoverished Nogat the channel is impassable for vessels drawing more than 3 feet. 3rd. That the ice-breakers have produced the desired effect of diverting all the largest ice-floes to the sea by the Dantzig branch; and 4thly. That the general result has apparently been to improve one branch of the river at the expense of the other.

In connection with the mouths of the Vistula, it should be further observed that the Nogat discharges itself into the Frische Haff by several very shallow channels near Elbing, where a lateral artificial canal permits steamers of small draught to enter the Haff and then to steer direct either for the mouth of the river Pregel, or for the port of Pillau on the Baltic. The entrance to this seaport has deepened itself 10 feet since the completion of its piers in 1846, and has now a depth of 24 feet; but from its harbour to the mouth of the Pregel, 19 miles, and thence for 4 miles further on, to the great corn-exporting port of Königsburg, the channels through the Haff and river only admit of the passage of vessels drawing less than 10 feet. Pregel.

The Oder rises in Moravia at an elevation of 1,000 feet above the sea, enters Prussian Silesia, traverses the provinces of Brandenburg and Pomerania, and after a course of 550 miles, empties its waters through the Stettin Haff or estuary into the Baltic (Plate 4). Its basin has an area of 50,000 square miles. The result of the large expenditure which has been incurred with the view of improving the navigation of the Oder, has thus far proved satisfactory. Works have been going on for some years past, and are now nearly accomplished, with the view of securing a depth of $3\frac{1}{2}$ feet between Ratibor, near the frontier of Silesia and Schwedt, 400 miles lower down. The other works of importance which have Oder.

lately been determined on in connection with this river, are: the extension upwards of the navigable channel from Ratibor to Oderberg; the construction of another Oder-Spree canal, leaving the Oder opposite the mouth of the Werthe; whilst a project for a ship-canal connecting the Oder and the Danube has been planned in detail, and its execution seriously entertained.

The estuary of the Oder may be said to begin at Stettin, from which place to Swinemünde, a distance of 50 miles, a channel has lately been dredged to a depth of 20 feet over a width varying from 250 feet to 400 feet, so that sea-going vessels of 19 feet draught can now trade with facility from the mouth of the Oder to Stettin without transhipment of cargo.

Elbe. The Elbe rises in the north-east of Bohemia, and one of its sources is about 4,500 feet above the level of the sea. It drains an area of 55,000 square miles, and next to the Rhine is the most important of German rivers. It enters the North Sea near Cuxhaven, and like the Duna, Niemen, Vistula, and Oder, its general flow is in a north-westerly direction. Its principal affluents are the Moldau and Eger, both of which enter the Elbe on its left bank above the Bohemian town of Aussig, not far from the German frontier. Notwithstanding the comparatively favourable state of the river at ordinary water-level, the condition of its bed in some places at extreme low water was so deplorable in 1870 that a technical commission, which was convoked at that time, recommended the execution of a project which had for its object the permanent acquisition of a channel of a minimum depth of 2 feet 10 inches from the Bohemian frontier downwards.

According to Mr. Ludwig Hagen, who has the supervision of all the Prussian streams, the minimum depths at ordinary water are now 5 feet from the Bohemian-Saxon frontier to the Saxon-Prussian frontier at Anhalt (163 miles), 5 to 6 feet from Anhalt to Havelburg (103 miles), and 6 to 6½ feet from Havelburg to Hamburg (121 miles). The practice of towing vessels of from 30 to 450 tons burden by men and horses between Aussig and Hamburg, has been almost entirely abandoned. As early as 1866, chain-tugs were running on 200 miles of its course, and in 1874 this mode of traction had been so much increased that there were then twenty-eight tugs running regularly between Hamburg and Aussig. These tugs are 138 to 150 feet long, 24 feet wide, with 18 inches draught. On the Upper Elbe the average tow is from four to eight large barges, and taking the ice into consideration, there are about 300 towing days in a year. On this river it has been found, as elsewhere, that vessels of large tonnage

pay best. Thus to the Hamburg Magdeburg Navigation Company (which has perhaps had more experience in the *modus operandi* of steam tugging in inland waters than any other corporation in the world) the cost of transporting a cargo from Hamburg to Dresden, a distance of 350 miles, for barges of 150 tons, 300 tons, and 400 tons is, respectively, 11*s.* 6*d.*, 9*s.* 9½*d.*, and 9*s.* 4*d.* per ton up stream, and 4*s.* 4½*d.*, 3*s.* 2½*d.*, and 2*s.* 9½*d.* per ton down stream. These figures are given on the authority of Mr. Bauer, and have been selected as a fair type of the present method of traction with its precise cost on one of the best conducted inland water routes on the continent.

The formation of an internal navigation to join the Elbe, the Oder, and the Vistula, has been successfully accomplished partly by the aid of secondary rivers and partly by canals. The canal of Müllrose unites the Oder and the Spree; the latter being a navigable river falling into the Havel, which in its turn falls into the Elbe near Havelburg. But the navigation from the Oder to the Elbe being difficult by this route, another communication was made by the Finow canal and a chain of lakes stretching from the Oder at Oderburg to the Elbe near Magdeburg. The Elbe being in this way connected with the Oder by a comparatively easy navigation, the latter has been united to the Vistula, partly by the river Netze and partly by a canal joining that river to the Brahe, which falls into the Vistula near Bromberg. A vast inland navigation has thus been completed, by which barges of 110 to 125 tons burden, and drawing 3 feet at ordinary low-water level, can pass freely through the whole extent of country from Hamburg to Dantzig.

Holstein Canals.

Before quitting the Baltic, a few words should be said with reference to an existing water communication across Holstein, and of a maritime canal which is shortly to be cut between Kiel and the mouth of the Elbe. The Holstein canal, formerly belonging to Denmark, is of great importance, joining as it does the Baltic with the river Eider, which falls into the North Sea. The Eider is navigable for vessels of 9 feet draught from Tonning, near its mouth, to Rendsburg, where it is joined by the canal which communicates with the Baltic at Holtenau, about 3 miles north of Kiel, the chief naval arsenal of Germany. The canal is 26 miles long, and the excavated portion is 52 feet wide at the bottom, and 9½ feet deep. It was opened in 1785 at a cost of £500,000.

The projected ship-canal is to run from the mouth of the Elbe near Glückstadt to a point near Kiel, and is to be of such dimensions as to pass the largest war vessels in the German navy from

sea to sea. When completed, this important undertaking will be of the greatest benefit to large steamers trading to the Baltic ports, and will supersede the present circuitous voyage by Jutland and the Sound, if the dues imposed are not prohibitory to the passage of merchant vessels.

Weser. The Weser has a length of 355 miles, and drains 18,000 square miles. In its upper part it traverses a mountainous district, and only emerges on the plain at Münden, whence to Bremen the distance is 230 miles. The system of improvement of the lower part of the river commenced in 1823 with the intention of securing a depth throughout of 1½ foot at extreme low water. Up to this time, however, the depth already obtained ranges from 1½ foot to 3 feet, thanks to the construction of an extensive series of groynes and training walls, and of a separate canal to avoid a difficult obstruction above Hameln. The barges now in use below Münden vary from 80 to 260 tons burden, and the proportion of laden vessels bound down stream is as six to one bound up stream. Works are in progress to still further improve the navigation of the Weser and its tributaries, especially the Fulda, down to Bremen, the second commercial town of Germany, situated on the right bank of the river about 50 miles from the sea. The depth of water at Bremen is only 7 feet, but at its sea port Bremerhafen vessels drawing 22 feet can enter safely, and, as at Hamburg, Bremerhafen is free from ice nearly all the year round.

Ems. The Ems rises on the confines of Lippe Detmold. It flows in a northerly direction, through Westphalia and Hanover, and empties itself through the Dollart estuary into the North Sea, near the town of Emden. It has a length of 200 miles, and is navigable for vessels of 200 tons to a distance of about 14 miles from its mouth, and for small vessels as far as the town of Rheine, 75 miles from the sea.

Rhine. The Rhine rises in Switzerland at an elevation of 7,240 feet above the sea, and its basin receives the drainage of 76,000 square miles. Its total length is 850 miles. It first becomes navigable for rafts at Reichenau, but thence to Basel, 820 feet above the sea, its navigation is difficult, and in many cases impossible, owing to the existence of numerous rapids and cataracts, of which that at Schaffhausen, 70 feet in height, is the most remarkable. At Basel the river trends to the north, and flows in that direction over a long flat plain to Mainz (310 miles from the sea, and 240 feet above sea-level) at the confluence of the Main. In this part of its course floods take place annually, but since 1840 this evil has been greatly remedied by the formation of a navigable channel

varying from 3 to 30 feet in depth, with high embankments confining the stream to a width of 807 feet. At Mainz the river again turns west along the south slopes of the Taunus, and at Bingen, where the navigation has been improved by the removal of rocks which formerly impeded the course of the river, it once more turns north, entering a narrow defile which it quits at Bonn to wind westward over a portion of the great German plain to Emmerich, a frontier town a little above the head of the delta. How the Rhine then breaks up into Rhine and Waal, Rhine and Yessel, crooked Rhine and Lek, and finally reaches the sea through several mouths on the coast of Holland, can only be well understood by reference to a large map of the Netherlands.

Between Mainz and Emmerich the average summer width of the Rhine is 1,300 feet, and its mean navigable depth 8 feet. At certain places, at extreme low water, in dry seasons, the available depth is not more than 2 feet, in spite of the large sums of money which have been spent by the German States during more than half a century on regulation works of magnitude, comprising dredging and blasting operations, and the construction of those massive parallel training dykes and groynes which are so noticeable to the eye of every traveller between Bonn and Basel.

The principal tributaries of the Rhine on the right bank are the Neckar and the Main, the latter of which is navigable for barges over the last 200 miles of its course. The Moselle on the left bank rises in the Vosges, and becomes navigable at Pont-à-Mousson in France, but is almost useless for navigation on account of its very tortuous course and of its shallow bar where it joins the Rhine at Coblentz.

There is another tributary of the Rhine, however, of small volume, but formerly of great importance, which, on account of its celebrated coal measures, great industrial resources, and certain physical peculiarities, deserves especial notice in any sketch, however slight, of German waterways. I refer to the River Ruhr, which joins the Rhine on its right bank near Duisburg, between the river ports of Düsseldorf and Wesel. The Ruhr is the water-road from the Westphalian coal districts to the Rhine. Its drainage basin, including that of its tributaries, the Lenne, Ennepe, and Volme, is 2,000 square miles. Its minimum discharge, is 300 cubic feet per second, and its maximum 58,245 cubic feet per second, or two hundred times more than its minimum volume—a very abnormal relation indeed. The navigable length of the Ruhr is 46 miles and its average and minimum widths are 164 and 68 feet respectively. The river has

eleven locks, 147 feet long and 18 feet 6 inches wide, and the barges traversing them draw 3 feet 6 inches, and carry 180 tons. During the period 1855–78, the navigation was interrupted either by ice or by floods, on an average from a maximum of one hundred and fourteen days to a minimum of twelve days. On this account, and on account of the low transit charges of the network of railways the importance of the Ruhr has become almost *nil*. Thus in 1855 there passed through the Ruhr lock at Mühlheim 750,000 tons, and in 1878 only 46,800 tons. Projects for the improvement of the navigation of the Ruhr have been made, but are not likely to be carried out. If anything is done it will be solely with the view of diminishing the floods. This recent information concerning the Ruhr was obtained for me from official sources by my friend, Mr. Henry Gill of Berlin, M. Inst. C.E.

In the first reach of the river above the delta of the Rhine, 12 miles below Emmerich, the width of the undivided river in summer is about 1,800 feet, and more than double that width in winter; the mean discharge being 89,000 cubic feet per second, and the maximum 341,000. At the apex of the delta extensive training works have been constructed to regulate the flow of the river after it leaves the German frontier, the object in view being so to distribute its volume, that in all states of flood, high as well as low, two-thirds thereof should be conveyed into the Waal, and one-third into the Lek or Lower Rhine. The navigable depth of the deltaic branches of the Rhine varies from 4 to 10 feet. An interesting account of the great works which have been constructed to regulate the flow of the various branches of the delta of the Rhine will be found in the Minutes of Proceedings Inst. C.E.[1]

Steam-towage is almost universal on the Rhine, and, as on some other rivers, a great difference of opinion exists as to the relative merits of paddle-tugs, chain-tugs, and wire-rope tugs. In 1873, a wire-rope tug company laid down the line from Bingen to Rotterdam and worked the upper section of 155 miles themselves, and in 1874, on the Neckar, five tugs were employed on a length of 56 miles. By means of canals the basin of the Rhine is connected with the basins of the Rhone and Saône, Scheldt, Meuse and Danube.

Canals. Although Germany possesses a length of nearly 17,000 miles of navigable rivers, or more than double the combined length of the navigable streams of France and the United Kingdom, it cannot be said to be rich in canals. In South Germany the Regnitz and

[1] Minutes of Proceedings Inst. C.E. vol. lix. p. 227.

Ludwig's canals, from the Main at Bamberg to the river Altmühl, an affluent of the Danube, were the only artificial waterways of importance until the annexation of Alsace-Lorraine. The North German Plain has several canals, the most important of which I have already referred to in describing some of the chief river systems of the Empire. In 1878 the total length of the seventy canals of Germany was only 1,250 miles, a very small extent when compared with the other canal systems of Western Europe.

## HOLLAND.

Holland has the great advantage of holding the mouths of the Rhine and the Meuse, or Maas, and the Schelde or Scheldt (Plate 4). The means of river communication with Germany, France and Belgium are numerous, and the possession of 930 miles of canals, 340 miles of rivers, and 1,130 miles of railways, enables a large trade to be carried out with greater facility of transport than in any other European country, with the exception, perhaps, of Belgium.

New mouth of the Maas.

Owing to the great improvements that have lately been carried out at the new mouth of the Maas at the Hoek of Holland, 18 miles from Rotterdam, vessels drawing 22 feet can already reach that port, and works are now in progress for the further improvement of the Lower Maas, which, when completed, will bring the total expenditure up to £2,500,000. Of the 3,765 vessels that made use of the new channel in 1884 70 had a draught of from 20 to 21 feet, and 10 of from 21 to 22 feet.

North Sea and Amsterdam Canal.

By means of the North Sea and Amsterdam canal, a full account of which will be found in Mr. Hayter's Paper on that great work,[1] vessels drawing from 23 to 24 feet are able to reach Amsterdam direct from the sea by a channel 15 miles long, and from 65 to 105 feet wide at the floor line. This canal, which cost upwards of £3,000,000, and for which Sir John Hawkshaw was Consulting Engineer, and Mr. J. Dirks, Resident Engineer, has now almost totally superseded the third and earliest great maritime highway of the Netherlands, namely, the North Holland canal, 52 miles long and 16 feet deep, from the Texel to Amsterdam. This, the greatest work of its day, was constructed in 1819–25 by Blanken, at a cost of nearly £900,000.

North Holland Canal.

Other canals.

The inland canals of Holland, which serve as arterial drains as well as for navigable purposes, are generally 60 feet wide at the

[1] Minutes of Proceedings Inst. C.E. vol. lxii. p. 1.

bottom and 6 feet deep. In places where their extremities are connected with the sea, they are closed by massive flood-gates to keep it out when it rises higher than the canal. It is worthy of remark that within the natural sand dunes and artificial dykes which protect the coasts of Holland and Belgium from the encroachments of the sea, not only is the surface of the canal but the bed itself frequently many feet above the level of the surrounding reclaimed land; and it is an interesting fact that the surface-level of the North Holland canal between Buiksloot and Purmerend is 4 feet below mean sea-level.

Through the kindness of Mr. J. Dirks, M. Inst. C.E., Engineer-in-Chief of the Waterstaat, I am able to direct your attention to a very interesting map of the Low Countries which he lately forwarded to me "with the object of explaining," to make use of his own words, "our singular but historic system of nomenclature; our rivers being cut up into longitudinal pieces like an eel."

## Belgium.

The surface of Belgium is generally level, and it is only towards the south-east that one finds a wild tract of country of small extent, but with elevations sometimes attaining a height of 2,000 feet. The principal rivers of Belgium are the Meuse and the Scheldt.

Meuse. The Meuse rises at a level of 1,350 feet above the sea near Langres in France, enters Belgium about 30 miles south of Namur, and on reaching that town receives its largest tributary, the Sambre, which almost doubles its volume. From Namur the course of the Meuse trends to the north-east, and continues that direction to Venloo, passing Liege and Maëstricht on the way. From Venloo it takes a north-west direction to Gorcum, where it joins the Waal branch of the Rhine. Its further progress to the sea is difficult to describe in a few words, and can be best understood by reference to Mr. Dirks' map. The total length of the Meuse, which is canalized at difficult places, is 580 miles, of which 460 miles are navigable.

Scheldt. This by far the most important river in Belgium, although its basin has an area of only 8,000 square miles, derives its origin in France, 10 miles north of St. Quentin, at an altitude of 360 feet above the sea, and is navigable for more than four-fifths of its course. On arriving at Ghent, where it receives its chief tributary the Lys, the tidal influence is first felt, and on reaching Antwerp the mean range of the tide is 13 feet 8 inches. At

the mouth of the Estuary (Flushing) the mean range is nearly 2 feet less, or only 11 feet 9 inches. According to information which I received on the spot in 1867, when charged by the British Government with a mission concerning an international question of engineering connected with the Scheldt, the scouring power of the tide at Antwerp is nine times greater than that of the fresh-water flow, the mean discharge of the latter being only 5,000 cubic feet per second over a width of 1,200 feet. Hence the great depth of the river at Antwerp of 24 feet at extreme low water alongside its noble range of commercial quays, which for extent and accommodation are unrivalled in any other port with which I am acquainted. Thanks to its unique position at the head of a tidal estuary, which, like the Thames, has no bar at its mouth; to the abolition of the Scheldt dues; and above all to the foresight and liberality of the Belgian Government, which has spent £4,000,000 sterling on dock and river works since 1877, Antwerp has now become in many respects the foremost port of the continent of Europe.

Besides her 700 miles of navigable rivers, and 2,634 miles of railways, Belgium possesses a length of about 540 miles of canals, by means of which an excellent system of water-communication exists between all the large towns and the chief seaports of the kingdom. By these artificial waterways also there is easy and cheap intercourse with Holland and with the chief towns in the north of France. On the authority of Mr. Von Borries, the cost of canal carriage from the Belgian coalfields to Paris was 0·29*d.* per ton-mile in the spring, and 0·34*d.* in the autumn of 1883, without paying interest. Canals.

## France.

My description of the chief rivers of France, so far as regards their navigable capabilities, must necessarily be very brief.

The Seine rises on the northern slope of the Côte d'Or, at an elevation of 1,460 feet. Its length is 480 miles, and it first becomes navigable near Troyes, about 350 miles from its mouth. Its principal tributaries are the Yonne and Eure on the left bank, and the Marne and Oise on the right, and by means of waterways it communicates with the Loire, Saône, Rhine, and Scheldt. Seine.

From Paris to Tankerville, at the head of the estuary, and 16 miles from Havre, the Seine is so winding in its course that whilst by water the distance is 220 miles, it is only 100 miles in a straight line. From Paris to Rouen, 150 miles by water and only 72 in a straight line, the river is studded with many islands, and its average fall

is 6 inches per mile. At Rouen the level of low water is only 10 feet above the sea. Until the end of last century the low-water depth of the Seine was only 2½ feet, and for nearly fifty years afterwards it was considered to be in a good navigable state when giving a draught of 4 feet. Between 1846 and 1865 numerous locks and weirs were constructed between Paris and Rouen to provide a depth of 5 feet, but before the works were completed it was decided to increase the draught to 6½ feet. The engineers, however, who were entrusted with this work, seeing its inadequacy, proposed increasing the draught to 10½ feet, so that vessels of 800 tons burden could come up to the Pont de la Concorde at Paris at all times, and the execution of a project with this end in view was decreed in 1878. At the present time, between the first lock at Surenne and the last one at Martot—15½ miles above Rouen—there are seven locks, the average distance between them being 15½ miles. The average rise of these nine locks is 8 feet 3 inches, the maximum at Martot being 13 feet 9 inches, and the minimum at Mericourt 6 feet 5 inches. The estimated cost of the improvements, which are still in progress, consisting principally of several new locks provided with movable weirs, is £1,700,000, including the provision of the same draught of water throughout the whole of Paris. At Bougival, 30 miles from Paris, the new lock is 722 feet long, and at Port Villez, 60 miles from Paris, the lock and weir, which together cost £235,000, were completed in 1880. The weir of this lock consists of two navigable passes 198 and 194 feet wide, and of an overfall 267 feet wide. Many interesting details concerning fixed and movable weirs in France will be found in Mr. Vernon-Harcourt's Paper on that subject.[1]

The navigation of the Seine from Rouen to the sea (76 miles) is both tedious and difficult, owing to its very sinuous course and to the numerous shoals which obstruct the shifting channel of its estuary, and it is with the view of rectifying this latter evil that a canal is now being made between Tankerville and Havre, so that ultimately vessels navigating the Seine above Rouen may reach Havre with expedition and at small cost. The canal will be at one level throughout, and is to have a lock at each end 590 feet long and 98 feet wide. The depth of the canal will be 10½ feet (3·25 metres).

With regard to traffic on the Seine, it was stated in 1872 by Mr. Krantz that the canalized river between Paris and Rouen carried 150,000,000 ton-miles, or more than one-eighth at that

[1] Minutes of Proceedings Inst. C.E. vol. lx. p. 24.

time of the whole water traffic of France, and about one-twenty-fifth of that of all the railways.

The mean discharge of the Seine is 24,500 cubic feet per second from a total area of 30,000 square miles. The discharge at Paris at high floods is 60,000 cubic feet per second, and 1,230 cubic feet at extreme low water. During the extraordinary high flood of 1876 the water rose 25 feet 3 inches at Paris and 13 feet 6 inches at Rouen.

The Loire rises in the Cévennes 30 miles from the course of the Rhone, and flows in a north-west and west direction through the centre of France to the Bay of Biscay. The mean discharge of the Loire is 34,800 cubic feet per second from an area of 44,000 square miles. Of its total length of 607 miles, 450 are navigable, but its chief tributaries, four on the left and one on the right bank, are of little service to the navigation, owing to their shallow and irregular channels. In the middle part of its course the Loire traverses some of the most beautiful scenery in France. In the lower part, which is subject to frequent and sometimes disastrous inundations, high embankments have been thrown up to contain the floods, and a lateral canal was completed in 1838 between Roanne and St. Brisson to afford the means of navigation at all stages of the river. Of all French rivers the Loire is the most irregular in its regimen, and therefore the most intractable as a navigable stream. Its bed, occasionally half filled for a day or two with sand-banks, intersected by serpentine channels, which are barely navigable for small river craft, becomes covered in a few days with from 20 to 24 feet of water. At such times the embankments are overtopped, many breaches are made in them, and the country is inundated far and wide. To give an idea of the great variations in the volume of water discharged by the Loire below the confluence of its chief tributary the Allier, I may state that, according to Mr. Reclus—to whom I am indebted for many of my figures concerning French rivers—the maximum discharge at floods is 353,000 cubic feet per second, and the minimum only 1,060; the mean being 10,600 cubic feet per second. Thus the extreme difference in the discharge of the Loire at the "Bec d'Allier" is from 1 to 330, or more than one-half greater than that of the river Ruhr, which, as has been already mentioned, is from 1 to 200.[1] The City of Nantes is the chief maritime port of the

Loire.

[1] Discharge of the Lower Loire, after Comoy, 1856, in cubic feet per second:—

| | | | | |
|---|---|---|---|---|
| Confluence of the Maine, | maximum discharge | 215,145; | minimum | 4,485 = 1 to 47 |
| Nantes . . . . . | " | 215,980; | " | 10,600 = 1 " 20 |

Loire, but owing to its shallowness ocean steamers of deep draught are compelled to load and unload 30 miles lower down stream, either at St. Nazaire or at Paimbœuf, close to the river mouth.

Garonne. The Garonne (615 miles in length) rises in the Pyrenees within the Spanish frontier, becomes navigable at Cazéres, is connected with the Mediterranean at Toulouse by a canal, and finally unites with the Dordogne about 13 miles below Bordeaux to form the large estuary of the Gironde, a tidal basin 50 miles long. The river frequently overflows its banks, and, owing to general shallowness and frequent changes in its bed, the inland navigation of the Garonne, and of its tributaries above Bordeaux, is subject to many difficulties, in spite of the generally successful results of the system of training works that has been adopted at several places, with the object of maintaining a depth of at least 7 feet in the artificially contracted channel without having recourse to dredging.

Vessels of 800 tons can trade to Bordeaux, but ships of larger burden can only ascend the Gironde as far as Pauillac on the left bank, about 30 miles below Bordeaux, and about the same distance from the Atlantic. The Gironde, which comprises the united waters of the Garonne and Dordogne, has a mean discharge of 41,000 cubic feet per second from an area of 35,000 square miles.

Rhone. The Rhone (635 miles in length) has its source in Switzerland, not far from the St. Gothard Pass, and enters France by the narrow defile of l'Écluse. Its upper course is both rapid and tortuous, and hardly navigable, until Lyons is reached at the confluence of the Saône. The Saône from its source in the Vosges flows south-west and south, and possesses an excellent system of navigation for 170 miles, through the lower part of its highly fertile valley. The chief towns on its banks are Beaune, a little above which the Saône and the Seine are connected by the Canal of Bourgogne-Chalon, where the Canal du Centre joins the Saône with the Loire and Mâcon. In the 200 miles from Lyons to the Mediterranean the Rhone falls 532 feet, giving an average of 32 inches to the mile. Notwithstanding this great inclination, the river is navigable the whole way for vessels of considerable burden excepting at extreme low water, when the depth is less than 3 feet in many places, or barely enough for the working of the steam-tugs on the grapne system, which are in constant use above Arles, a large town at the head of the delta, and 175 miles from Lyons. The charge for up-river transport between these two places is $\frac{1}{2}d.$ per ton per mile.

The Rhone has a mean discharge into the sea of 60,600 cubic feet per second from an area of 38,000 square miles. Its maximum

discharge is 423,840 cubic feet per second, and its minimum 19,426 cubic feet = 1 to 22.

The improvement of the Rhone as far as Arles from the new Mulatière dam (525 feet long and 52½ feet wide) at the junction of the Rhone and the Saône,[1] so as to ensure everywhere a depth of 5 feet 3 inches (1·60 m.) at low water, is now in progress, and a grant of £1,800,000 has already been obtained for this work. The project is a combination of the two systems of regulation and canalization, and the cost of improving the navigation throughout on this principle is estimated by Mr. Pasqueau, the author of the project, at £2,250,000. Between Arles and the Mediterranean the minimum depth of the channel is about 6 feet, or as much as exists on any one of the bars at the mouth of the river.

Lateral Canal at mouth of Rhone.

To avoid these bars, after having tried unsuccessfully to deepen one of them by the system of parallel piers, which for want of being carried sufficiently far seaward never had a fair chance of success (although such a chance would have been but a feeble one if, as has been stated on good authority, there is no littoral current), the Government resorted to the expedient of cutting a lateral canal 2 miles in length, and furnished with a lock, from the tower of St. Louis to the neighbouring Bay of Repose (Plate 4). By means of this work, the annual maintenance of which has not been onerous, vessels drawing up to 19 feet have been able to enter the Rhone since 1862, when the canal was completed at an expense of £620,000 including quays. As a work of art, the canal (which I visited more than once whilst under construction) reflects great credit on Mr. Pascal, Inspector-General of Roads and Bridges, under whose direction the works were executed.

With regard to the condition of the Rhone as a navigable stream, Mr. Reclus stated in 1879, that "before the construction of the Lyons and Marseilles Railway, the navigation was very important, but that since that time it has never been able to compete with the railway; in place of sixty-two steamers, which were always employed in carrying goods from one port to another, there are now only eight boats employed in carrying an annual freight of little more than 200,000 tons."

General system of Canals.

With but few exceptions, the earliest of the canals in France were laid out solely with reference to local interests, and were

[1] Relative discharge of the two rivers at their confluence at Lyons, in cubic feet per second—

| | Extreme low water. | Mean. | Extreme floods. | Proportion low to high. |
|---|---|---|---|---|
| Rhone . . . | 8,830 | 22,958 | 211,920 | 1 to 24 |
| Saône . . . | 2,119 | 8,830 | 141,280 | 1 „ 66 |

therefore as a rule, badly adapted for economical transport over very long distances. On the other hand, since 1821–22, when the most important canals of the country were designed, and their execution decreed, French waterways have been dug down to a uniform depth of 5 feet 3 inches (1·60 metre) over a bottom width of 33 feet (10 metres), with the view of giving the cheapest and most direct means of transit between great centres of trade far apart from each other. In the north, the Seine is placed in direct communication with Belgium, by the river Oise which the canal of St. Quentin prolongs to Mons, and the canal of Charleroi to the town of that name. On the other hand, the canal of Ardennes unites the basin of the Seine with that of the Meuse, and consequently again puts it in communication with Belgium and Holland. In the west, a network of canals, commencing at Nantes, puts Brittany in direct intercourse with the naval ports of Brest and L'Orient; and, by the Loire, with the centre of France. In the East, Paris is in direct communication with Nancy and Strasburg by the Marne and Rhine Canals. In the south, the lateral canal of the Garonne and the Canal du Midi unite the Atlantic with the Mediterranean and Bordeaux with Cette. This latter port is also in direct communication with the Rhone by means of canals to Aigues-Mortes, and Beaucaire.

Languedoc Canal.

The celebrated canal of Languedoc, now an integral part of the Canal du Midi, was built in 1667–81 (eighty years before the opening of Brindley's Bridgewater Canal) by Riquet, the greatest engineer of his day. It has a length of 171 miles and a depth of 5 feet 3 inches, and its highest part is 600 feet above the sea. From this summit level it communicates with the Garonne, and therefore with the Atlantic, by twenty-six locks, and descends the southern slope by seventy-three locks to the Mediterranean.

Dimensions of locks for new and improved canals.

With reference to the Canal du Midi, I have the authority of Mr. Malézieux, Inspector-General of Roads and Bridges, for stating that, like all the canals in France classed as principal lines of communication by the law of 1879, it is to be deepened to 7 feet 4 inches (2·20 metres) or its level is to be raised in such a way that vessels drawing 6 feet 6 inches (2 metres) may be able to pass through it without delay. The same decree also prescribes that the locks of all the principal canals shall have a clear length of 126 feet (38·50 metres) and a width of 17 feet (5·20 metres), with sufficient water on their sills (now fixed at 2·50 metres) to allow the free passage of vessels drawing 6 feet 6 inches (2 metres).

According to the returns of Mr. Krantz, member of the National Assembly for inquiring into Internal Navigation in 1872, the length, cost of construction, and of transport were then as follows:—

Length and cost of waterways, with their traffic and cost of transport.

Total length 8,120 miles, of which 3,123 miles were canals, and 4,997 rivers.[1]

Cost of construction £46,295,867, of which £32,738,715 for canals, and £13,557,152 for rivers.

Cost of transport with tolls, 0·324*d.* per ton per mile for canals, and 0·420*d.* for rivers.

Ibid., without tolls, 0·243*d.* per ton per mile for canals, and 0·324*d.* for rivers.

To complete Mr. Krantz's information and to bring the mileage of French waterways, already made and still to make, down to a later date, I quote the following from a tabular statement by Mr. Conder.

| | Miles open in 1878. | Miles to open. |
|---|---|---|
| Basin of the Seine | 1,582 | 233 |
| „ Rhone | 994 | 201 |
| „ Loire | 1,979 | 774 |
| „ Garonne | 1,324 | 328 |
| „ Gulf of Gascony | 272 | 162 |
| Channel and North Sea | 576 | 59 |
| Charente and Sèvre Niortaise | 342 | 56 |
| Total open and to open | 7,069 | 1,813 |

Grand total, 8,882 miles.

Total cost of 7,069 miles of waterways, £43,608,516.

From the foregoing, it would appear that in 1878 France had spent considerably more than double the sum spent by the United Kingdom (£19,145,866) up to 1844 in the improvement of inland navigations. Nevertheless, comparatively large as had been her expenditure in this regard up to 1878, a Bill was deposited in that year in the Chamber of Deputies for still further systematizing and improving the internal navigation at an estimated cost of £40,000,000.

From the "Bulletin des Travaux Publics, 1881," an interesting comparison has been made by Mr. Petit, concerning the three great trade routes in France. Mr. Petit's summary is as follows:—

[1] Mr. Krantz remarks that "the 'rivers' included in this statement are not all strictly navigable, and that the length of those portions which are suitable for navigation does not exceed 5,700 kilometres" (3,524 miles).

| Transit Routes. | Length. | Tonnage. | | Proportion of Tonnage. |
|---|---|---|---|---|
| | | Mean. | Kilometric. | |
| | Kilometres. (Miles.) | | | Kilo. |
| Railways . . . | 24,383 (15,141) | 415,394 | 10,801,259,457 | 75 |
| Navigable rivers . | 11,986 (7,432) | 182,000 | 2,174,531,000 | 15 |
| Highways . . . | 37,462 (23,264) | 39,400 | 1,480,148,000 | 10 |
| Total . . | 73,813 (45,827) | 196,000 | 14,455,938,457 | 100 |

This Table shows that although in 1880 the length of inland navigations was one-half that of railways, the amount of traffic carried by them was only one-fifth. On the other hand, taking the cost of railways at £30,000 per mile, and £6,000 as that of canals as capital, and the figures 415,394 and 182,000 in the above Table as representing traffic, the contrast is evidently and strikingly in favour of canals even in their unimproved state.

The total length of French railways in 1884 was 16,886 miles, as compared with 5,262 miles in 1860, being an increase of 320 per cent. in the last twenty-four years.

## Spain and Portugal.

The chief rivers of the Iberian Peninsula are eight in number. Five of them, the Minho, Douro, Tagus, Guadiana, and Guadalquiver, drain the western valleys, and flow into the Atlantic; and the other three, the Ebro, Jucar, and Segura, drain the eastern valleys, and discharge their waters into the Mediterranean. The high mountain ridges and elevated plateaux which Spanish rivers have to descend give them a rapid course, so that in general they are of comparatively little use for navigable purposes, and running, as they often do, in very deep beds, are frequently unavailable for purposes of irrigation.

Tagus. The Tagus drains an area of 37,500 square miles. Taking its rise on the borders of Aragon and Castille, it dashes down to the plain of Zarita, and thence, flowing tranquilly through the Royal Gardens at Aranjuez, at an elevation of 1,700 feet above the sea, passes with quickened velocity the old walls of Toledo, Talavera, Alcantara, and Abrantes, and finally, after a course of 570 miles from its source, empties itself into the Atlantic, about 7 miles below Lisbon. Unfortunately for commerce, the Tagus is only navigable to the Portuguese frontier, or about 120 miles

from the sea. Opposite Lisbon, on the south shore, is Cassilhas Point, or the eastern extremity of what may be called the Port of Lisbon, whence a wide expanse towards the north opens out into a magnificent harbour, of from 2 to 7 miles in breadth. At the Point itself the river is 1 mile wide, but it narrows to $\frac{3}{4}$ mile at Belem, on the north bank 2 miles below Lisbon, whence it expands again to a width of nearly 2 miles at its mouth. The bar has a depth of from 6 to 7 fathoms at low water of spring tides, and the channel within it soon deepens to 19 fathoms. Notwithstanding this great depth, however, the bar is impracticable in south-westerly gales, and in winter, or when the freshets are strong and accompanied with westerly gales, continues so for several days together.

The Douro is 485 miles long, and drains an area of 37,000 square miles. Its direction is generally west, and it traverses the most mountainous portions of Leon and Salamanca before it reaches the Portuguese frontier. Thence to the sea, the channel is everywhere narrow, with a rocky bed, and the water, being confined, the current frequently exceeds 9 miles an hour at times of thaw and heavy rains. Instances have already been given of great oscillations in the volume of discharge in the rivers Ruhr and Loire, but these may be termed insignificant when compared with the variations in the volume of the Douro. On one occasion, in 1860, when the river rose to the level of 33 feet 9 inches above low water of spring tides at the suspension bridge, $3\frac{1}{2}$ miles from the sea, the velocity equalled 16 knots an hour, and the discharge 995,000 cubic feet per second, or two and a half times as great as the highest flood-discharge of the Tagus. At the same bridge, and according to the same authority, Mr. A. J. Nogueira Soares, the lowest discharge in the summer months of 1875 was only 700 cubic feet per second. Douro.

Mr. Soares, in stating these phenomena, is justified, therefore, in declaring that there is probably no other river of importance where so great a flood-rise takes place so near the sea, or where the volume of fresh-water discharge varies from 1 to 1,500. During spring tides, he adds, the total tidal outflow does not exceed 35,300 cubic feet per second, or about one-thirtieth part of a great river flood.

The depth of water on the bar of the Douro, between the years 1874–78, averaged 14 feet 6 inches at low water, or 25 feet 6 inches at high water of spring tides. Oporto, the second city of Portugal, stands on the side of a steep eminence of about 200 feet elevation, which rises from the north bank of the Douro about

2 miles from the sea. The river is navigable for 70 miles from the entrance, and boats of light draught can proceed 30 miles higher. Grain and other produce are floated down from Spain on flats, but navigation is often interrupted by heavy floods.

Guadalquiver. The Guadalquiver rises on the borders of Murcia, drains 22,000 square miles, has a length of 375 miles, and occupies the centre of the plain that lies between the Sierra Morena and the chain of Granada. In the upper part of its course it intersects the rich province of Andalusia, and after pursuing its way through pestiferous swamps to Cordova and Seville at last forms a harbour near its mouth, above the seaport of San Luca de Barrameda, whence Columbus sailed on his third voyage to America in 1498, and Magellan on the first voyage of the circumnavigation of the world in 1519. The Guadalquiver is navigable for vessels of 100 tons, at certain seasons of the year, up to Seville, 70 miles from the sea, but, as a rule, vessels of more than 10 feet draught are obliged to load and unload about 8 miles below the city. The channels between the shoals at the mouth of the river are only practicable for small vessels.

Guadiana. The Guadiana rises in La Mancha, and after passing through the province of that name, flows on to Merida and Badajoz. A little below the latter it turns to the south and enters Portugal, through which it flows for nearly 100 miles, and then, again washing the frontier of Spain, forms the boundary of the two kingdoms to the sea. The area of the basin of the Guadiana is 25,000 square miles. Although 316 miles in length, the river is only navigable up to the town of Mertola, about 40 miles from its mouth at Villa Real. The entrance to the Guadiana is encumbered with shoals, and at low water there is only a depth of about 6 feet on the bar, or 18 feet at spring tides. Within the bar, however, off Villa Real, where the river is ½ mile broad, the depth is 27 feet.

Ebro. The Ebro rises in the province of Santander, and drains 39,000 square miles, and after a course of about 470 miles, empties itself into the Mediterranean, about 15 miles east of the town of San Carlos de la Rapita. It receives one hundred and fifty tributaries, and its chief towns are Tudela, Saragossa, and Tortosa. At Amposta, 20 miles below Tortosa, the river divides and runs into the sea by two branches. In order to facilitate the communication with the sea, a lateral canal, 10 miles long and 5 feet deep, runs south from Amposta to San Carlos, at Port Alfaques, where there is room for a large number of vessels not drawing more than 18 feet. The principal commercial utility of the Ebro is the transport of grain from Saragossa to Tortosa, together with the floating down of

timber from the Pyrenees. Owing to the shallow channels of the Delta, however, and to the numerous sandbanks at its mouths, only vessels of very light draught are able to pass the bars, and hence the navigation of the Ebro, although the largest river in the peninsula, is not very important. As a source of supply for irrigation, however, the Ebro, like the majority of Spanish rivers, is of more value in this respect than as a navigable stream. Its bed is rocky, and its current above the influx of the Segre, its principal affluent on the left, much disturbed by rapids and cataracts; and though this evil has been remedied in part by the construction of a navigable channel, the Imperial Canal from Tudela to a point 20 miles below Saragossa, yet the obstacles to navigation are still great; and whilst its use as a source of supply for irrigation is increasing, its volume for navigable purposes goes on decreasing in the same degree.

Besides the navigable canals connected with the Ebro, there are only worthy of special mention the canal of Segovia, connecting that town with the river of the same name, and the canal of Castille, to unite Santander with the Douro, a work, however, which is only partly finished. According to Millet, the total length of navigable canals in Spain was only 130 miles in 1875. On the other hand, the length of her railways was 5,600 miles in 1884. Canals.

## ITALY.

Italy is not rich in waterways except in the valley of the Po. The navigable portions of her rivers—the most important of which will shortly be described—have only an aggregate length of 1,100 miles.

The Po rises at 6,560 feet above the sea, and in a course of 350 miles drains an area of 29,000 square miles. At a distance of 20 miles from its source it enters the plain of Saluzzo, between which and Turin, a distance of only 30 miles, it receives three considerable tributaries. The Dora, which flows past Susa at the foot of Mount Cenis, unites with the greater river a little below Turin, and the Sesia joins it 25 miles below the confluence of the Dora. About 30 miles still further on, the Po is joined by the Ticino, which brings with it the overflow of Lake Maggiore. Its next great affluent is the Adda, which flows through Lake Como; then comes the Oglio from Lake Iseo; and finally the Mincio runs in near Mantua from Lake Garda. At its confluence with the Mincio, the Po has a width of from 1,200 to 1,800 feet, and it then con- The Po.

tinues to flow on in an undivided stream to its first bifurcation near Ponte Lagoscuro, and thence on to Maria de Ariano—about 25 miles from the sea—where it parts into two arms, and these again are subdivided into several other branches, forming an extensive delta about 20 miles in width from north to south. The growth of the delta since the time of the Romans is very marked. The town of Adria, which was then a maritime town, now stands on the banks of the Po 20 miles inland, and it has been estimated that from the year 1600 to 1800, the delta advanced at the rate of 225 feet annually. On the other hand, to the north of the delta, there is equally good evidence of the encroachment of the sea on the land.

The Po is continuously embanked from near Cremona to the marshes at its mouths. At its highest flood the water rises 24 feet above extreme low water at the confluence of the Ticino; 26 feet near Piacenza; 20 feet at Cremona; and 28 feet at Ponte Lagoscuro, 4 miles above Ferrara, where the level of low water is only 9 feet above the sea, from which the old city is now removed 50 miles, or 20 miles further from the coast than two thousand years ago. Hence it is that the top of the embankments at Ferrara is higher than the roofs of the houses. The prevention of the lateral spread of the water in floods by dykes is said by many engineers to occasion the deposit of sediment in the channel, and consequently to cause an elevation of the bed, which requires the embankments to be raised proportionally; but Lombardini has shown that the effect of this on the Po is by no means so considerable as has been often represented, and that in the middle lower course of the river the bed of the proper low-water channel is subject to so little permanent change of level as to have now become substantially constant.

The mean discharge of the Po is 60,745 cubic feet per second, its maximum 181,580, and its minimum 7,558 cubic feet per second, or a ratio of 1 to 24. The waters of the Po are very heavily charged with detritus, and, according to Mr. Boccardo, the volume held in suspension is at times $\frac{1}{300}$ of the volume of water discharged.

The Po is navigable from its mouth for vessels of 130 tons up to Valenza, 600 feet above the level of the sea, and 7 miles below the confluence of the Sesia, and below the confluence of the Oglio the depth of the main river at extreme low water is never less than 5 feet 10 inches; but as most of the transport which would otherwise be carried on by means of its channel is now effected by railways, of which Italy possessed 5,651 miles in 1883, the river

has lost much of its relative importance as a route for commercial communication.

The Adige rises in the Tyrolean Alps, and drains 5,400 square miles in a length of 234 miles. Flowing southward it passes by Trent, and enters Lombardy. After passing Verona, it flows nearly south-east, and pursues a course parallel to that of the Po till it enters the Adriatic by an independent mouth about 13 miles north-east of Adria. The waters of the two rivers have been made to communicate by artificial cuts at several places. The Adige is navigable from its mouth to Trent, but the velocity of the current impedes the navigation. The Adige.

The Tiber rises in the Apennines at a height of 3,805 feet above the sea, and drains 6,500 square miles, and after a course of 240 miles, generally in a south direction, empties itself into the Mediterranean through two mouths about 16 miles south-west of Rome or 24 miles by the course of the river (Plate 4). The mean discharge of the Tiber is 10,800 cubic feet per second, and its minimum discharge 5,800 cubic feet per second.[1] The Tiber.

Rozet has calculated that the advance of the delta for many centuries past has kept steadily at the rate of 13 feet per year. The estuary, which originally formed the harbour of Rome, was so reduced in depth by silt from the river and sand rolled in by the sea, that it was found necessary in the days of the Empire to cut a channel from a point about 1½ mile above Ostia (the ancient sea-port of Rome, and now 2½ miles inland) to the coast, at a place called Fiumicino, situated at 2 miles N. of the chief disemboguement of the Tiber, now called the Bocca di Fiumara. The artificial canal—known as the Fiumicino branch—(on the north bank of which are the remains of the once famous ports of Claudius and Trajan) is still the only navigable channel between the Mediterranean and Rome, the old Fiumara mouth being obstructed by constantly-shifting sandbanks.

The rise of the Tiber in its great floods is very considerable, and is measured from the zero of the gauge at the Ripetta stairs at Rome. This zero is 4 feet above the level of the sea. The lowest known surface of the Tiber at the stairs is 17½ feet above zero, and its mean height 22 feet. In the inundation of 1870, when I was on a visit to Rome, the waters rose to 56

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[1] The proportion of the minimum to the maximum flood has been variously estimated by Italian engineers as being from 1 to 25 to 1 to 30; or from a minimum discharge of 3,500 cubic feet per second to a maximum of 105,000 cubic feet. According to Mr. Vescovali, the discharge of the Tiber has never been less than from 5,600 to 6,300 cubic feet per second.

feet 6 inches above zero, and as the pavement of the Ripetta and that of the adjacent streets is only about 44 feet above zero, all the north-west quarter of the city, including the Corso and other important business streets, was overflowed, to a depth near the river of about 12½ feet, and the direct and indirect damage occasioned by the flood, which was the greatest on record since 1637, could hardly be over-estimated. Numerous schemes have since been proposed to prevent the recurrence of a similar disaster. Grave objections have been made to many of these projects, but on one point all engineers seem to agree—and this principle is now being practically carried out—the expediency of widening and straightening the channel at various points within and near the limits of the city, of carefully regulating the outflow of drains into the river, and of removing from its bed the numerous artificial obstructions, chiefly piers of old bridges, and accumulated rubbish of centuries.

The Tiber is navigable from the sea to Rome for vessels of 140 tons, and, with some difficulty, 60 or 70 miles further for vessels of 60 tons. At the Fiumicino mouth of the river the entrance is narrowed between parallel piers so as to increase the scour over the bar, but the available depth on it is rarely more than from 6 to 8 feet.

Canals. The Italians were the first people in Modern Europe who attempted to plan and execute canals. As a rule, however, they have been principally undertaken for the purpose of irrigation. The total length of the navigable canals is 435 miles. The most important are the Cavour Canal, in Piedmont, which, supplied from the Po, begins at Chivasso and terminates at Turbiga, a distance of 52 miles; the Grand Canal, in Lombardy, supplied from the Ticino, near Tornavento; the Canal of Pavia, also supplied from the Ticino, and passing through Binasco; the Canal of Martesana, which, from Milan through Gorgonzola, leads to Cassano on the Adda. The provinces of Polesina in Venice, of Padua, and the Emilia have all excellent canal systems. In Tuscany the most important are those of Pescia, Pisa, and Ombrone.

### Austria-Hungary.

As the highlands of Austria form part of the great watershed of Europe which divides the waters flowing north into the North Sea or Baltic, from those running south or east into the Mediterranean or the Black Sea, all Austrian rivers of note flow either north, south or east. All her great river mouths, moreover, are situated

in other countries, and one of them, the Danube, has its source as well in a neighbouring State. The courses of its chief streams, namely the Dnieper, the Vistula, the Oder, and the Elbe, have already been summarily passed in review, and it therefore only now remains for me to describe the course of the Danube to complete the list.

### The Danube.

The Danube is the largest river in Europe as regards volume of discharge, but is inferior to the Volga in the length of its course and the area of its basin. It rises in the Black Forest at an elevation of about 3,600 feet above the sea, and drains 316,000 square miles, its total length being 1,750 miles.

From the mouth of the Iller, which divides Würtemburg and Bavaria, the Danube is fed by at least three hundred tributaries. On the right bank, the chief of these, with their drainage area in square miles, are: the Inn (9,600), the Drave (14,300), and the Save (37,500), and on the left bank the Theiss (60,000), the Olta (9,000), the Sereth (18,000), and the Pruth (10,000). Together, these seven streams have a length of 2,900 miles and drain one-half of the whole extent of the Danube basin. Tributaries.

### Upper and Middle Danube.

The upper part of the river first becomes navigable, for flat bottomed boats carrying 100 tons, at Ulm, 130 miles from its source, and only a few miles below the confluence of the Iller, its first tributary of any importance. Ulm.

At Kelheim, half way between Ulm and Passau, the Danube communicates with the Rhine by means of the Ludwig Canal, and the rivers Altmühl, Regnitz and Main. The canal is 110 miles long and 7 feet deep, and was completed in 1844 by King Ludwig the First of Bavaria. From Ulm to Passau (220 miles), at the mouth of the river Inn, which doubles the volume of the main stream, the Danube traverses the great Bavarian plain, but thenceforward it flows through a mountainous region till it reaches Vienna. In this distance of 406 miles of the lower section of the Upper Danube the river has been considerably improved by works of correction, and vessels drawing 4 feet can now navigate the whole distance at low water, excepting at the Fischament-Theben rapids, where the depth is occasionally reduced to 3 feet. Ulm to Vienna.

At Vienna, which is situated on the right and left banks of a branch of the Danube (164 feet wide and 4 feet deep at low water) River diversion at Vienna.

at an elevation of about 520 feet above the sea, and at a distance of 1,208 miles from the Sulina mouth, the main stream of the river has been brought 1½ mile nearer to the city by a new channel 10 miles long, 1,000 feet wide and with a depth of from 10 to 12 feet below ordinary low-water level (Plate 5). This great cut involved the removal of 12,000,000 cubic metres of sand and gravel, and, with all its subsidiary work, cost £3,250,000. The enterprize was established by an Imperial Commission in 1866, and the proposal to construct the regulation on its present plan had the able support of Mr. James Abernethy, Past-President Inst. C.E.

The cutting has been very successfully carried out, and has already been of great service, not only in protecting Vienna from disastrous floods, the principal object of the scheme, but in improving the railway communications and the navigable capabilities of the river at this portion of its course.

Further particulars of this interesting river diversion, written by the Engineer-in-Chief, Ritter Von Wex, are published in our Abstracts of Papers in Foreign Transactions.[1]

Proposed Danube and Oder Canal.

The construction of a deep canal, about 150 miles long, from a point on the left bank about 6 miles below Vienna, to Oderburg on the river Oder, has lately been under serious consideration, and the execution of this project bids fair to become an accomplished fact at no distant day.

Vienna to Old Moldova.

From Vienna the Danube flows east for 150 miles through a wide expanse of plain country to Waitzen; and then turning south pursues that direction through the great plain of Hungary by numerous windings to Esseg situated at the confluence of the Drave, 347 miles below Vienna, and 165 miles below Buda Pesth. This imposing-looking capital of Hungary is situated on the right and left banks of the Danube at 182 miles below Vienna, 152 below the confluence of the March at Theben, the frontier of Austria-Hungary on the left bank; 146 from Pressburg; 89 from Gönyö near the confluence of the Raab; and 21 from Waitzen. From Esseg the river trends south-east to Semlin (140 miles), the lower frontier town of Hungary on the right bank at the confluence of the Save, and immediately opposite Belgrade, the capital of Servia. Hence to Old Moldova (76 miles), and then on to the Hungarian-Roumanian frontier at Old Orsova (63 miles) the river flows nearly due east. At Old Moldova, it enters a series of rocky gorges, unequalled in Europe for their grandeur; and after

[1] Minutes of Proceedings Inst. C.E. vol. xlvi. p. 294.

sweeping through a succession of deep pools and shallow rapids, confined within the grand passes of Stenka, Izlaz, and the Kasan, finally reaches its last and most formidable rapid called the "Iron Gates," 632 miles from Vienna, and 582 miles from the Black Sea.

Proposed improvements.

Although the Danube, from Vienna to Old Moldova, has also been regulated in numerous places and at great cost, by narrowing and training works, consisting of groynes, dams, and longitudinal dykes, there has been but little appreciable improvement effected in its general navigable depth. On this account, projects, having in view the permanent acquisition of a sufficiently wide channel of from 6 to 8 feet deep at every point between Passau and Old Moldova, have lately been prepared by Government Engineers, which involve an outlay of £2,000,000 to effect the desired improvements, the principal of which would be the permanent removal of the Fischament-Theben, and the Pressburg-Gönyö shoals.

Condition of existing navigable channel.

With the exception of a short stretch of the river near Gönyö, the existing channel between Vienna and Old Moldova affords a minimum depth of from 4 to 5 feet, during nearly two-thirds of the year (taking the ice into consideration); but at Gönyö itself, the navigation during the dry season is so difficult that a depth of from 3 to 5 feet is only maintained by Mr. Murray Jackson's excellent system of steam-raking, a full account of which will be found in our Minutes of Proceedings.[1]

Rapids below Old Moldova.

The Danube between Old Moldova and the Iron Gates (69 miles), 6 miles below Orsova, the frontier town of Hungary, is traversed at eight different places by reefs of sharp-pointed rocks, which render the navigation difficult at ordinary low water, and altogether impracticable at the lowest water season. These serious natural obstructions have hitherto been the great barrier to the free development of traffic on the middle and lower Danube, and the existing slackness of trade at this part of the river will continue, and possibly increase, until its navigable condition has been radically improved. These so-called Cataracts of the Iron Gates, which are wholly within the territories of Roumania and Servia, have a length of 5,070 feet, with inclinations of 1 in 507 at high, and 1 in 307 at low, water; the extreme variations between high and low water being 14 feet 6 inches at the head and 22 feet 6 inches at the foot of the falls. The level of low water at Old Moldova is 201 feet, and at the foot of the Iron Gates, 118 feet above sea-level. This fall of 83 feet in 69 miles gives an

[1] Minutes of Proceedings Inst. C.E. vol. lx. p. 387.

inclination of 1 in 4,400, as compared with 1 in 2,220 between Passau and Vienna, and of 1 in 10,000 between Vienna and Old Moldova.

Projects for overcoming rapids.

For more than a quarter of a century projects have been made for surmounting the difficulties between Old Moldova and the foot of the Iron Gates, by four different systems of treatment, namely, by open cuts; by simply narrowing the channel; by excavated channels confined within submerged and insubmergible walls; and by a combination of one or more of these plans, aided by one or more lateral canals.

The latest project is that of an International Commission of Engineers named by the Austro-Hungarian Government in 1879. This Commission proposed to establish a channel 2 metres deep at extreme low water, at every point between Old Moldova and Turn-Severin by means of cuttings 60 metres wide through the upper seven shoals, and to construct a lateral canal at the Iron Gates on the Servian shore, provided with two lift locks (508 feet by 118 feet) to overcome a difference of level of 14 feet 6 inches at that place. The cost of the open cuttings was estimated at £350,000; the improvement of the Iron Gates at £530,000.

Widths and velocities of current below Vienna.

The width of the Danube between Vienna and Basias (15 miles above Old Moldova) varies from 2,000 to 6,000 feet at low water, and from 7 miles to 30 miles at high water; but to this statement exception should be made of Peterwardein (50 miles above Belgrade), where the entire volume of the river, at high and low water, flows through a channel 40 feet deep, and only 800 feet in width. At this spot, 777 miles from the Black Sea, the Danube is crossed for the last time by a railway bridge, or, indeed, by a bridge of any kind whatever. At the Kasan, a pass 5½ miles long, where the granite cliffs rise to a perpendicular height of nearly 1,000 feet, and where the depth is 80 feet in the dry season, the mean width of the river is but 600 feet, and the difference between extreme high- and low-water level as much as 23 feet. The mean velocity of the current from Vienna to Basias is 2 knots an hour, and 3 knots at high water, but at the narrow defiles of the Kasan and Izlas it attains 8 knots at high floods.

Chief tributaries.

The Hungarian central section of the river is fed by the Drave, the Theiss, and the Save.

Save and Drave.

With regard to the Drave and the Save, I have only time to remark that their improvement has never yet been attempted; that the former is navigable in its natural state to the confluence of the Mur (150 miles), and the latter to Sissek (370 miles), and that their lengths from their sources in Illyria to Esseg and Belgrade are 434 and 535 miles respectively.

The Theiss, or Tisza, falls into the Danube on the left bank, between Peterwardein and the confluence of the Save, and is navigable for a length of 475 miles to Tokay. It would require the time allotted for a whole lecture to give anything like a detailed description of this remarkable affluent, and therefore, in the few minutes at my disposal, I can only sketch its chief characteristics in the briefest possible manner. It rises in the Carpathians, and its basin drains one-fifth of the great valley of the Danube. Half a century ago it had a total course of 828 miles, and from Tisza Uylek, where it ceases to be a mountain stream, and enters the great Hungarian plain, a course of 750 miles. The length of its valley from Tisza Uylek is only 372 miles, so that, like the lower Seine, its length was double that of the plain through which it flowed. From Tisza Uylek to Szegedin (621 miles) the fall was 136 feet in 621 miles, or 1 in 24,500; and from Szegedin to the mouth of the river, 129 miles, only 8 feet, or 1 in 73,000. Between 1832 and 1879 the cut-offs executed by the Government for the principal purpose of protecting the adjacent lands from inundations, were one hundred and thirteen in number, of an aggregate length of 83 miles. These cuts shortened the river 300 miles below Tisza Uylek, and cost £690,000, exclusive of a further sum of £2,000,000, which was spent by local companies on 1,000 miles of embankments. According to the report of Mr. Herrich, Ministerial Councillor, the result of these great works has been to protect an area of 4,200 square miles, out of a total area of 6,000 square miles of low ground, from floods; but from no authority can I glean any information concerning the effect of the cut-offs on the navigable condition of the river. Unfortunately, however, one fact is but too well known, namely, the great disaster of 1879, when the large town of Szegedin, at the confluence of the river Maros, was almost totally destroyed, and many of its inhabitants swept away by an unprecedently heavy flood. It should be added that the Maros enters the Theiss at a bad angle, and has also been greatly reduced in length—from 430 miles to its present length of only 162 miles. Theiss.

The two chief canals in Hungary are the Bega, 75 miles long, joining Temesvar with the Theiss at Tetel, a little above its junction with the Danube, and the Franz Josef, 69 miles long, which stretches from the Danube at Battina by Zombor to the Theiss near Foldvar. On the latter canal the traffic increased from 246,000 ton-miles in 1876 to 600,000 ton-miles in 1878, but it has never yet, I learn, paid any interest to its shareholders. Canals.

According to Mr. Lanfranconi, whose Papers on Hungarian rivers,

with excellent maps thereof, may be referred to with advantage in our library, Austria-Hungary possesses 2,104 miles of waterways made up as follows:—

| | Miles. |
|---|---|
| Passau to Orsova | 817 |
| Drave, Thiess, and Save | 1,013 |
| Raab and Inn | 48 |
| Canals | 226 |
| | 2,104 [1] |

Traffic on the Upper and Lower Danube is mostly carried in barges belonging to the Imperial and Royal Danube Steam Navigation Company, of which they possess about eight hundred, the greater portion having a carrying power of 250 tons. The mean annual traffic up-stream from Belgrade to Pesth is 600,000 tons, or about as much as by rail. The barges have been built in recent years entirely of steel, and have generally a length of 180 to 190 feet, with 24 feet beam and 8½ feet depth, and their displacement is 120 tons without cargo. The largest steamers are from 220 to 250 feet in length, with from 25 to 27½ feet beam and 10 feet deep at the sides, with a slight displacement of 440 to 460 tons.

Haulage is performed on the Upper and Central Danube by steam-tugs and chain-tugs; and it was with the view of obtaining some authentic information on this important subject that I applied some time ago to Mr. Murray Jackson, late Chief Engineer of the Danube Steam Navigation Company, for a short statement of the result of his long and varied experience regarding the relative merits of each mode of traction. Mr. Jackson has obligingly furnished me with some valuable "Notes" on "Water Traction by Steam Power," which are too long to repeat at this advanced hour; but I trust the Council will permit them to appear hereafter in the shape of an Appendix to my lecture, should the latter be considered worthy of publication.

## Lower Danube.

The Lower Danube begins at the foot of the Iron Gates (Plate 5), and terminates in the Black Sea, from which it is distant 340 miles in a straight line, and 580 by the windings of the river. The left bank from Verciorova, the Roumanian frontier town (2½ miles from the Hungarian frontier town of Orsova) to mid-channel of the Pruth (11 miles below Galatz), is Roumanian territory; and from mid-channel of the Danube, opposite the mouth of the Pruth,

[1] The total length of railways open for traffic in Austria-Hungary in January, 1884, was 12,223 miles.

the frontier of Roumania is conterminous with that of Russia (according to the Treaty of Berlin of 1878) to mid-channel of the Danube at Ismail Chatal, and thence to mid-channel of the Kilia branch at Wilkov, where the Kilia branch spreads out into several subsidiary channels (Plate 5). From the village of Wilkov the frontier follows the mid-channel of the Stary Stamboul, the most southerly of the branches of the Kilia delta, till it reaches the sea, at a distance of about 10 miles north of Sulina. The right bank of the river from the confluence of the Save at Belgrade to the mouth of the Timok at Rakovitza (59 miles below the Iron Gates) is in Servia; from Raovitzak to Silistria (284 miles) it is in Bulgaria, and thence to the sea, following the St. George's branch, in Roumania. Thus both banks below Silistria belong to the Roumanians, with the exception of the left bank from the mouth of the Pruth to Wilkov, and thence to the sea by the Stary Stamboul branch. The fall of the river from the Iron Gates to Sulina gradually becomes less, as in the lower part of all large rivers flowing through their own alluvium, as it reaches the sea. Thus between the Iron Gates and Tchernavoda, 388 miles, with a difference of level of 103 feet 6 inches, the inclination is 1 in 19,800; between Tchernavoda and Ibraila, 76 miles, with a difference of 11 feet, 1 in 36,500; whilst between Ibraila and Sulina, 116 miles, with a difference of only 3 feet 6 inches, it is reduced to 1 in 175,000.

### 1. *Iron Gates to Ibraila.*

At the Roumanian town of Turn-Severin, on the left bank, 8 miles below the Iron Gates, are still to be seen, at extreme low-water, thirteen of the twenty stone piers of a bridge that was built across the Danube in A.D. 103 by Apollodorus, the architect who built Trajan's column at Rome. The river here is about 3,000 feet wide, and the maximum depth 18 feet. From Turn-Severin to Widin, 83 miles, its course is very tortuous, but the general direction is to the south. From Widin, however, to Tchernavoda, 297 miles, its general trend is to the east. The river leaves the mountains behind at Widin, whence, to Ibraila, the left bank is everywhere flat and uninteresting. The right bank, on the contrary, is bordered by high banks as a rule, to the sea, and generally presents a landscape pleasantly varied by headlands, gentle slopes, and cultivated enclosures. Nicopoli, 122 miles below Widin; Sistov, 25 miles below Nicopoli; Rustschuk, 37 miles below Sistov; and Silistria, 68 miles below Rustschuk, all situated on considerable elevations on the right bank, and all famous as great battle-fields

between the Russians and Turks, have each corresponding towns on the opposite bank, but the only one worthy of special notice is Giurgevo, the Port of Bucharest, and formerly the *tête du pont* of Rustschuk.

Tchernavoda. At Tchernavoda, 45 miles below Silistria, the width of the main river is 2,000 feet, and its depth at low water 28 feet. The extreme variation between high and low water is 23 feet, the latter having here a level of 14 feet 6 inches above the sea. When the floods attain a height of 18 feet, the whole country is inundated (for the river below the Iron Gates is nowhere embanked), and its width expands across the Balta or island to the village of Fetesci, 8½ miles, to the high left bank of a subsidiary branch of the river, called the Borçea, which, leaving the Danube opposite Silistria, again joins the main stream 31 miles below Tchernavoda. Elaborate competition projects, presented by Belgian, French, German and Swiss Engineers, have for some time past been under the consideration of the Roumanian Government for bridging the Borçea at Fetesci, and the main river at Tchernavoda, which was surveyed under my direction in 1882, so as to join Bucharest with Kustendjie, but although two of these projects were considered worthy of high commendation no decision has yet been come to as to the precise dimensions of the structures to be erected.

The Danube at Tchernavoda, 210 miles from Sulina, is separated from the port of Kustendjie on the Black Sea by an isthmus only 40 miles wide, and if a waterway were cut to that seaport in the line of the existing railway or Trajan's Wall, the distance by water from Tchernavoda to Constantinople would be shortened 263 miles; the distance from Sulina to Constantinople being 311 miles, and from Kustendjie to Constantinople only 218 miles. In 1837, surveys were made and a series of levels taken of this part of the Dobruja with the view of constructing a canal across the isthmus, but the scheme was abandoned on ascertaining that the summit level was 164 feet above the sea, and that no adequate supply of water could be obtained from the neighbouring high lands to fill the locks that would be required to overcome the difficulties of the ground between the river and the sea. In 1857, an English company obtained a concession from the Sublime Porte to construct a railway, instead of a canal, and in 1860 the Tchernavoda Kustendjie Railway was opened for public traffic. Although well managed, it never prospered, owing to the impossibility of competing successfully with the Sulina route in its improved condition, and, in 1882, the line was sold to the Roumanian

Government, and it is now worked by the State. It may here be added that, in 1884, the length of railways in Roumania already constructed was 850 miles, and the length under construction 340 miles. The charge of the railway for grain discharged from up-river craft at Tchernavoda, then cleaned by machinery and loaded into wagons, and finally shipped at Kustendjie, after being transported over 40 miles of railway, has generally been 4*s.* per ton—a charge by no means excessive—and yet, with but very few exceptions, vessels pass Tchernavoda and go straight on to Ibraila or Sulina; for in practice it has been found either more economical or more convenient to take the longer water route. This is another example showing how in certain cases preference is given to a very circuitous waterway instead of to a direct route by land.

On leaving Tchernavoda, the Danube bends to the north and continues that direction to Galatz (13 miles below Ibraila) whence it flows east by south to the sea.

The river between the Iron Gates and Ibraila has frequently a depth of over 40 feet at low water, but at seasons of very low water its bed is encumbered in several places by sandbanks on which the depth is not more than 9 feet, and at three shoals, Nicopoli, Sistov, and Tchernavoda, not far below the railway station, the depth is at extreme low water reduced to 7, 6, and 4½ feet respectively. Still the navigability of this long stretch of the Danube, which has never yet been "doctored" by an Engineer, may be considered in a good condition compared with other European rivers of anything like the same importance.

Between the Iron Gates and Ibraila, the average width of the main Danube (for here it splits into many branches forming numerous islands) before it floods its natural banks, is about ½ mile. The extreme difference between high and low water varies from 24 feet 6 inches at Turn-Severin to 23 feet at Nicopoli, and 19 feet 6 inches at Ibraila.

### Danube from Ibraila to the Sea.

In obedience to the special request of my friend the President, I shall now inflict upon you a *mauvais quart d'heure* in describing the nature and intention of some of the regulation-works which have been carried out under my direction as Engineer-in-Chief in what may be called the maritime section of the Danube, since the conclusion of the Crimean war—at which epoch the river below Ibraila was in a state of nature, that is to say, unruly and entirely untrained (Plate 5).

varies from a minimum of 12 grains to a maximum of 840 grains per cubic foot of water, or 1 to 70. The mean annual discharge of sediment by the Sulina is 5,000,000 tons, the proportion in weight to that of water giving an average of about $\frac{1}{3,000}$.[1]

When the improvement of the Sulina branch was first decided upon, its course of 52 miles was impeded by eleven bends, each with a radius of less than 1,000 feet, besides numerous others of greater radius, and its bed was encumbered by ten shifting shoals varying from 8 to 13 feet in depth at low water. The width of the upper part of the branch varied from 500 to 800 feet, and that of the lower half from 600 to 750 feet. In the first case shallows existed wherever the width exceeded 500 feet, and in the second there was no appearance of a shoal where the width was limited to 600 feet. Consequently the first projects which aimed at securing a minimum depth throughout of 15 feet were designed to narrow the river to the width that nature herself seemed to indicate as sufficient to maintain the depth desired. Experience, however, has since shown the necessity of narrowing the channel to 400 feet in the upper section, and to 500 feet lower down, in order to maintain the depth obtained either by dredging or natural scour.

Owing to a want of funds the Commission was only in a position to proceed slowly with the river-works, and many years elapsed before a clear gain of 4 feet in depth could be obtained throughout the branch. During that period of transition it was proved over and over again that dredging, although often resorted to to give temporary relief to the navigation, was altogether inadequate to ensure a permanent improvement, for, owing to the vast amount of detritus carried in suspension, as well as to the sand rolled along the bed of the stream, the shoals, which were still untouched or but partially treated, were invariably in process either of augmenting in volume and height during floods, or of deepening and diminishing in bulk as the water subsided. Occasionally a shoaling of from 2 to 3 feet would take place, when no particular reason for its formation could be assigned, and until the unexpected obstruction was removed by dredging much inconvenience was experienced by the navigation.

River works of correction.

Time only allows me to give a very meagre description of the river works which have been constructed to regulate and fix the channel, and two examples must suffice as types of the methods which have been employed, as a rule, to attain the end in view.

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[1] The mean annual discharge of sediment of the whole river before it divides at Ismail Chatal, in the ten years ending 1871, was 67,760,000 tons, the maximum discharge (1871) being 154,000,000 tons, and the minimum (1866) 12,500,000 tons.

The object of the first works was to confine the waters within certain limits where required, so that the floods might operate in deepening the channels sufficiently, but not so violently as to cause excessive scour, an effect which only gives an abnormal deepening, not needed, at the expense of the river lower down where the depth is already insufficient for the navigation. As before remarked, this "*juste milieu*" of width was found in practice to be 400 feet in the upper half of the Sulina and 500 feet in the lower half, and these widths have accordingly been adopted. The worst shoals in the Sulina branch, before its correction was taken in hand, were found at St. George's Chatal and at Algany, 3 miles lower down. The latter being then the worse of the two was attacked first, and will be first described.

Algany shoal.

In its natural state the shoal extended from bank to bank, a width of 700 feet, and the depth over it at low water was only 8 feet. The first works consisted in the construction of several low groynes or spurs from the left or concave bank, and in the closing of a subsidiary stream. These preliminary works produced an appreciable improvement in the first instance, but as two years afterwards the shoal began to deteriorate, it was then decided to confine the river within artificial works 500 feet apart carried up to the full height of the banks. This was accomplished by the construction of a curved longitudinal dyke joined to the left shore by a straight groyne and by the projection of several other groynes and a small longitudinal work from the right bank. The channel was dredged at the same time, as, unlike most of the other shoals, the bottom consisted of hard clay which resisted the erosion of the current. Notwithstanding this treatment, a depth of from 13 to 14 feet could only be maintained by occasional dredging, and it was not until the channel had been narrowed to 400 feet that the existing depth of 15½ feet could be constantly maintained without further artificial aid. The groynes, as at all the other shoals, are composed of fascines of willows or reeds bound together with iron wire on frameworks of timber sunk *in sitû* and revetted with stones from the bed of the stream up to level of high water. The root ends of these spurs speedily become incorporated with the river banks, but their outer ends require careful maintenance to protect them from the attacks of ice in winter when the navigation of the Lower Danube is generally suspended for a period of two or three months.

St. George's Chatal.

In my first project for the correction of the Sulina branch, I recommended the opening of a new entrance from the Toultcha branch favourable in its direction for the navigation, and intended

to supersede the old entrance at St. George's Chatal, which was difficult both of ingress and egress, owing to its exceedingly tortuous and shallow channel. This scheme lay on the shelf until the improved finances of the Commission enabled it under my advice to undertake the work in 1880, and to complete it in December 1882. The state of the old Chatal underwent many vicissitudes, until it was finally abandoned. For want of money nothing but dredging could be done in the early years of the Commission to maintain the channel at the depth of 12 feet at zero or lowest water. In 1865, however, this constantly recurring expense was found to be so unsatisfactory, and the persistent erosion of the Chatal point by strong currents and floating ice became so alarming, as to cause me to advise the Commission to lose no time in constructing protective and training works at the Chatal, and to exhaust every legitimate endeavour to improve it before resorting to the plan of cutting an entirely new entrance, which, at such a delicate point, would entail a certain amount of risk, and an outlay which could be better applied for the moment in the construction of still more urgent corrections down stream. My proposition being accepted, the first work was begun in 1865, and consisted of the revetment of the concave bank, and a continuation of the latter on the same curve, 600 feet, by means of what may be called a half-tide spur of rubble stone 350 feet long, terminating in the Toultcha branch at a depth of 16 feet at zero. The spur effectually stopped any further erosion at the Chatal point, but failed to give any additional depth, and it was not until the work was crowned with a palisade of timber brought up to the level of high floods, combined with the projection of a half-tide straight groyne from the opposite bank, thus narrowing the pass to 450 feet, that an appreciable deepening of the channel occurred. This improvement continued until 1870, when the descent of an extraordinary high flood threw down such a mass of deposit at the Chatal that the available depth was at once reduced to 8 feet at zero, thus diminishing the depth of the channel fully 4 feet in less than three weeks' time. This rapid shallowing, following a gradual improvement of five years' duration, seemed to prove that the width between the curved spur and the opposite bank was still too great at times of high flood to prevent injurious deposit at the Chatal channel, and therefore the straight groyne was at once raised to the level of the river bank. This additional work, together with dredging, soon restored the channel to its former condition, and the improvement continued until April, 1875, when the survey showed a fairly good channel of 15 feet at zero.

Shortly after that time, however, the depth again began to fluctuate between 11 and 14 feet, and these constant changes in the bed of the stream, added to the inherently vicious direction of the entrance itself, became at length so intolerable to the long steamers which now trade to the Black Sea ports, that urgent demands were made for the cutting of an entirely new entrance. This request, as we have seen, was complied with.

New cutting at St. George's Chatal.

The new cut, ½ mile above the old Chatal, has a length of 3,300 feet, an average depth of 24 feet, and a bottom width of 300 feet, with slopes of 1½ to 1 and 1 to 1. It was begun in June, 1880, and its contents of 1,057,000 cubic yards of clay and sand were removed by the aid of dredgers, floating tubes, and hopper barges by December 1882, when the new channel was opened to the navigation. In the four following months there was a silting up of 3 feet in the new channel, and of 4 feet in the old one, owing to the velocity of the current in both channels being considerably less than in the reach immediately below them, and it was not until the old branch was entirely closed by a solid dam that the *régime* of the lower part of the Sulina branch was restored. An accelerated current swept away the recent deposits in the new cutting in proportion as the dam in the old branch was raised to the water-level, and within two months of its completion the whole mass of sediment, 187,000 cubic yards, an accumulation of less than six months' duration, was swept away by natural scour. The new channel then assumed the normal area of the improved sections of the river, and, with but few modifications, has retained it to the present time.

Improved condition of the Sulina branch and mouth.

The programme of the Commission for improving the navigation of the Lower Danube is on the eve of completion. Between the ports of Ibraila and Sulina there is now everywhere a navigable depth of from 17 to 20 feet at the season of high water, and a minimum depth of 14 feet at low water. In the Sulina branch nine of its worst shoals have been successfully dealt with, three cut-offs have been made, by which the river has been shortened 2 miles, eight of its worst bends have been entirely suppressed, and a length of 10 miles of stone revêtement to protect the banks has been constructed. The total cost of these river works, including maintenance and dredging, has not exceeded £300,000.

At the Sulina mouth, where there was only a depth of from 8 to 10 feet before the construction of the piers, the depth for many years past, unaided by dredging, has not been less than 20½ feet. The cost of the piers, including their maintenance to the present time, has been about £220,000.

Effect of improvements.

The effect of these improvements has been to increase the trade from 680,000 gross tons in 1859, to 1,530,000 gross tons of 2,240 lbs. in 1883, and to lower the charges on shipping from an average of 20*s*. per ton for lighterage before the deepening of the Sulina mouth and the improvement of its branch to less than 2*s*. per register ton at the present time for Commission dues.

Barge Transport.

Two-thirds of the trade are now carried by English steamers, which usually ascend to Galatz and Ibraila at ordinary high water to discharge merchandise or coals, and to load with grain. At seasons of low water they prefer, as a rule, taking in their cargoes at Sulina from iron lighters drawing from 8 to 12 feet, and carrying cargoes of from 300 to 1,000 tons. The average charge for conveying grain down stream by these lighters, which are towed by steam-tugs from Ibraila to Sulina, exclusive of loading and discharging, is 0·20 of a penny per ton per mile, and 0·33 of a penny per ton per mile for the transport of coals from Sulina to ports up stream.

Criticism on original projects.

It may be encouraging to young engineers who have difficult river and sea undertakings on hand—in the ultimate success of which they themselves have implicit faith—to learn that the works I have just described are almost identical with my first projects in 1857, which were emphatically condemned in 1858 by an International Commission of distinguished engineers—who had never visited the ground—in the following terms:—"The Commission cannot recommend the application of the proposed system of improvement, which offers no guarantee of success. As for the projects for the Sulina mouth and branch, they ought not to be carried out: their success is very uncertain; they will be of no real use; they will cause the total loss of very large sums of money, and will even throw obstacles in the way of the existing navigation." And even in stronger terms than these they condemned my plan of provisional piers at Sulina, which in three years' time (1858–1861) increased the depth on the bar from 8½ feet to 17 feet, at an expense of only £86,000. These provisional works, they reported in 1858 to their Governments, "should be immediately abandoned, if already commenced, for not only would they be useless for the purpose intended, but the guiding-piers themselves would speedily be destroyed by the force of the waves, owing to their feeble section." [1]

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[1] As a substitute for the parallel pier system at the mouth itself, the Technical International Commission recommended the construction of a lateral canal 16 feet

As a commentary on the above, I need only draw attention to two facts, namely, that the execution of the works so unsparingly criticised in 1857, has already effected a saving of upwards of £20,000,000 sterling, and that experience has abundantly proved that the predictions of a rapid silting up to seaward of the Sulina piers, which were so prevalent at one time, were happily unfounded; for, on the contrary, the entrance was never so free from sandbanks as at this moment, as will be seen at a glance on referring to the last survey of the Sulina mouth in November 1884. Commentary.

I cannot quit this subject without calling to mind the eminent services of my steadfast old friend, Col. Sir John Stokes, K.C.B., R.E. (whom I am happy to see in front of me to-night), whose prompt and energetic action at moments of financial and other difficulties, which beset the European Commission of the Danube during the fifteen years from 1856 to 1871 that he acted as H.M.'s Commissioner, has contributed more than anything else to the complete success of the governing body, which for the last twenty-nine years has exercised almost sovereign power on the lower part of the river.

And now, I am happy to say, our bad quarter of an hour is at an end, and that it only remains for me to conclude my lecture by a few practical observations, which have suggested themselves to my mind, on reviewing the facts which I have ventured to bring under your notice this evening.

It may have been remarked that I have taken some pains to ascertain the actual available depths for navigation in the principal inland waterways of Europe. This procedure has involved a considerable amount of correspondence with some of my colleagues at home and abroad, to whom I take this opportunity of tendering my grateful acknowledgments for the kind manner in which they have responded to my solicitations, for certain precise information, within their personal cognizance. The question of improved inland waterways is one that eminently deserves the attention of English engineers; but, unfortunately, since the establishment of the railway system in this country, the construction of canals and the improvement and canalization of

deep to the St. George's branch of the Danube from a point on the sea-board about ½ mile to the north of St. George's mouth, at an estimated cost of £360,000. If this plan had been executed, the cost of the canal up to this time, including maintenance, would have amounted to at least £600,000, and the navigation, instead of enjoying as at present a depth of 20½ feet at a wide, open mouth, would have been compelled to enter and leave the Danube through a narrow locked entrance of solid masonry with only 16 feet of water over its sill.

rivers has ceased to be appreciable. Such, however, is not the case abroad. On the great inland navigations on the Continent the permanent acquisition of even a single foot of additional depth between great trading ports in the same or in an adjacent river basin, is considered of immense importance, and worthy of being attained at a great cost; and striking examples of this assertion, in France and Germany, I have endeavoured to lay before you. In no other way than by deepening existing channels and by acquiring new ones of comparatively great depth, can a wholesale and wholesome competition with railways for the transport of heavy goods be brought about. With regard to the permanent deepening of large rivers without the aid of locks, the question is a very difficult one, and, fortunately for civil engineers, there is no golden rule to effect this grand desideratum; for every river must be studied *per se*, as it by no means follows that a system of improvement that has answered well at one spot, will be equally successful at another. Where a large river has many shifting shoals throughout its course, it is comparatively an easy matter to get permanently rid of one, two, three, or even more of them; but the crucial difficulty, especially in rivers heavily charged with detritus, is to get rid of every one of the shallows down to a depth where water transport can successfully compete with railways.

If, for instance, only a single shoal remains, which demands transhipment at certain seasons of the year between two important seats of trade on the same river, that shoal, like the weakest link in a chain, which is the measure of its strength, will be the real standard of the value of the river as a navigable highway. Again, until rivers in different basins are radically dealt with so as to ensure a sufficient navigable depth at all seasons, it is almost useless to join them by constructing canals deeper than the river channels they connect. Thus, for example, the Ludwig Canal joining the Danube and the Main can never be profitably worked until the navigable channel of those rivers has been very materially improved, and the same remark applies to the proposed canal between Vienna and Oderburg, at the ends of which the Danube and Oder have but comparatively shallow navigable channels. It goes without saying, that intractable rivers can only be profitably dealt with, by using them as feeders for lateral canals furnished with locks, or by canalizing the rivers themselves, with ample provision by means of movable dams or otherwise to enable the floods to pass freely without detriment to the navigation. In either case, apart from the question of depth, the locks should

wherever practicable have dimensions approaching those now being constructed on the Lower Seine. It need not be added that another element required to enable a canal to prosper as a great carrying highway is a great increase in speed, an improvement which can only be accomplished by enlarging the sectional area of the canal; by the best known mode of traction, and by protecting the banks against pernicious erosion.

As I remarked at the beginning of my lecture, it has not been my intention to discuss the relative cost of rail and water conveyance. Railways will prosper where water communications languish, when the latter labour under great physical difficulties, as on the Rhone and the Ruhr, and where, as in the United Kingdom, canals are handicapped by frequent lockages and insufficient sectional area.

On the other hand, waterways will flourish, as on the Seine, in Belgium, and in Southern Germany, where the winters are comparatively short, where tolls are merely nominal, where locks are large and infrequent, and where a good navigable depth is constantly maintained, so that vessels of large tonnage—*the great desideratum* in economical water transport—can nearly always be profitably employed.

I have abstained advisedly from alluding in this discourse to the Corinth Canal, now in progress, or to certain well-known projects for overcoming Isthmian difficulties of a like nature elsewhere, either by means of artificial water-channels, or by ship railways. It is one of the traditions, I believe, of this Institution, to discourage anything like a serious discussion, within these walls, of public works that are still in embryo, or under construction, and of course I shall not attempt to infringe this salutary unwritten law. I may remark, however, with regard to such great enterprizes, that whatever may be their ultimate fate, the number of great Isthmian schemes must necessarily be very limited, and that in this respect they differ materially from ship canals of an inland and therefore of a less ambitious character. Whatever, for instance, may be the result of the Liverpool and Manchester scheme now before Parliament, it is evident, I think, that a grand future is open to works of that class; and I venture to predict that the improvement of water communications between the sea and inland towns of importance, by means of canals or of deep, open channels planned so as to *aid nature* in maintaining permanently their increased depth, will continue to go on briskly after the last ghost of a practicable inter-oceanic waterway has been finally laid.

Sir FREDERICK BRAMWELL, President, said the lecture had brought before the members information from an enormous area of the civilized world, information obtained by great labour, but given to Sir Charles Hartley with that readiness which every engineer would feel disposed to entertain towards a request coming from a man so distinguished in his profession, and especially in that branch which had formed the subject of the lecture. He would not occupy their time longer except to ask them to return their hearty thanks to Sir Charles Hartley for the lecture he had given.

Sir JOHN COODE, Vice-President, said it was only those who had undertaken the labour of preparing a lecture on any subject who could have an idea of the trouble and time entailed in bringing together such a host of facts of great value, and he was quite certain that the lecture would be most useful as a reference to any one who might be interested in the subject of Inland Navigation. He had great pleasure in seconding the vote of thanks.

The resolution was carried by acclamation, and was acknowledged by Sir Charles Hartley.

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[APPENDIX.

# APPENDIX.

## DATA CONCERNING CHAIN-TUGS.

By Murray Jackson.

The advantages of towing on a submerged cable are, from a mechanical point of view, clearly understood. It is, however, too often forgotten that in order to realize them a very considerable outlay has to be incurred. This outlay is proportionate to the length laid down, and to the weight of the chain. The chain requires renewing in ten years, and taking this into account, together with the cost of maintenance, repairs, and interest of capital, 15 per cent. on the original outlay may be reckoned as the price of the advantage gained by the chain on the paddle. On the Elbe and on the Danube the chain first laid down was $\frac{7}{8}$ths of an inch in diameter. Repeated breakages caused the substitution of one of 1 inch in diameter. On the latter river this chain is of the very best "special" iron, and consists of short links $4\frac{1}{2}$ inches long and $3\frac{1}{2}$ inches wide; the weight being nearly 1 kilogram per link, or say 24 tons per English mile. The chain was made and laid in lengths of 100 yards, each end being provided with a shackle. The breaking strain was guaranteed at 30 tons, and each separate length of 100 yards was subjected to a test of 10 tons, whereby no permanent elongation or set was caused. The cost per mile of this chain was about £600 (including 12 per cent. for government duty on foreign chain) laid down in the river; and taking the length laid down between Pressburg and Vienna, at 40 miles (the real distance being 38 miles), including the necessary slack, the cost was £24,000. Owing to the freezing of the river, extraordinary high water periodically—during which the use of the chain is suspended—and other causes, the number of days actually worked does not exceed three hundred in each year. Taking, then, 15 per cent. on the outlay, this amounts to a charge of £12 per day for the use of the chain. In the case of the best paddle-tugs running between Pressburg and Vienna the slip of the wheel, taken at one-third the breadth of the float from the outer edge, is in no case more than 50 per cent. The time occupied by the tugs is on an average twelve hours, and as the current averages 4 miles an hour, the distance from Pressburg to Vienna, 38 miles, is in effect increased to 86 miles, during which the way passed through by the wheel is 172 miles. The useful effect of the latter therefore is reduced to 22 per cent. Supposing, in the case of the chain-tug, the load to be equal to that towed by the paddle, the resistance would be equal, provided the former likewise took twelve hours for the trip; and supposing no loss to arise from the chain, the proportion of power required for each would be as 4·5 to 1. The slack of the chain and slip may be taken at 10 per cent., but in addition to this a considerable loss of power arises from the friction on the rollers and on the hauling drums, &c. In practice the time of running on the chain from Pressburg to Vienna is fourteen hours, and the maximum load is 1,000 tons in four barges; while the load taken by the paddle-tugs consists of 500 tons in two to three barges, or about one-half. Comparing the cost of the one mode of towing with the other, the coal burnt per trip by the chain-tug can be taken at 90 to 95 cwts., while the paddle-tug requires 180 to 190 cwts. As two such tugs are wanted to take up 1,000 tons (taken by chain-tug) this is increased to 360 to 380 cwts. The proportion of coal burnt is therefore 4 to 1.

Assuming, further, the whole transport to amount yearly to 300,000 tons, which could be taken up on the chain by one departure daily, and would on the other hand require two paddle-tugs daily, the comparison could be easily made as follows:—

| | Cwts. | £. |
|---|---|---|
| 300 trips on chain from Pressburg to Vienna—coal | 27,000[1] = | 1,080 |
| 15 per cent. on chain . . . . . . . . . . . . | = | 3,600 |
| | | 4,680 |
| 600 trips with paddle-tugs, 108,000 cwts. coal . . . . | = | 4,320 |

If the amount of traffic were doubled, and 600,000 tons were transported yearly on the chain, two chain-tugs daily would be required. The cost of transport by the chain would be £5,760 against £8,640 by four paddle-tugs daily, showing a saving of £2,880 for double the traffic, thus converting a loss into a great gain. If with this amount of traffic the length of chain laid were doubled, the cost of transport would be £11,520 against £17,280, showing a saving of £5,760, or double that by the shorter chain, *i.e.*, for half the distance. It may be noted, although it has been taken for granted, that two paddle-tugs are requisite to do the work of one chain-tug, this is not strictly speaking the case. At times when the chain-towing is interrupted, for instance at times of high floods, the paddle-tugs can, and do run, making the service regularly. The chain-tug is likewise more helpless, and requires assistance in getting together her convoy, and cannot well be used for intermediate stations without loss of time. Again, it often occurs that the chain-tug has to make the trip with considerably less than the maximum load. The greatest drawback to the chain-towing on a long line of navigation, when it has only been partially introduced as on the Danube, lies, however, in the fact that the tugs can only be used where it is laid, whereas the paddle-tug is free to work wherever required. Trade may be good on the Save, while little is doing between Pressburg and Vienna. The paddle-tugs which can be spared may be sent there at once, while the chain-tugs cannot be so made use of. The Danube tugs do not use the chain in running down the stream, but are fitted for that purpose with feathering wheels, and can now take down the barges which they tow up. On no other river are chain-tugs fitted with paddles, which are of great advantage, as not only is the chain in a strong current of no use in descending the river, but its employment for several reasons has been found objectionable. On the Elbe the whole of the goods downwards are carried on barges without the aid of steam. In returning the barges are for the most part empty, or only partially loaded, and make use of the chain-tugs to tow them up stream. The current is very much less than on the Danube. With paddle-tugs it is very important that the load taken is not excessive, but proportioned to the power and force of current, otherwise a great loss is occasioned by slip.

[1] Price of the Company's coal is taken at 16*s.* per ton at Pressburg, about 40 kreutzers in gold.

16 April, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

# "Tides and Coast-Works."

By THOMAS STEVENSON,[1] President of the Royal Society of Edinburgh, M. Inst. C.E.

I CANNOT but express my sincere regret, on your account, that Sir John Coode should have been prevented, by unavoidable causes, from giving the lecture on "Tides and Coast-Works"; and all the more, as so short a time has been at my disposal for meeting this unfortunate emergency. I trust, however, you will kindly make, for me, as great an allowance as possible.

As regards the very important but also very abstruse subject of the tides, which forms the first part of the matter which has been remitted to me by the Council, I believe it is not expected that I should enter systematically into it, the more so as there are many treatises which fully embrace all the details in so far as the extent of our knowledge and the state of mathematical science enables the investigation to be undertaken. I may refer in particular to the remarkable Treatise on the "Tides," in the "Encyclopædia Metropolitana," by Sir John Herschel, and also to the works of Airy, Laplace, and Newton.

It seems only necessary, by way of preliminary remark, to note the confusion which has been introduced into the subject, by neglecting to take into consideration the large lapse of time, between the passage of the moon across the meridian and the time of high water, due to the inertia of the water, and the irregularities of the shores and bottom of the sea, in connection with what is called the "Establishment of Ports," or what is generally termed the times of high water on the days of full and change of the moon. As is now well known the tides do not occur syn-

[1] As Mr. Stevenson was unable to attend through indisposition, this discourse was read by Mr. Eaton.

chronously with the passage of the moon across the meridian, but lag behind for about three or four tides. Another great cause of confusion has arisen from the difference which exists between the phenomena of the flow and ebb of the currents and the vertical rise and fall of the tides; and then again there are many tides which are not directly due to the attraction of the moon, but are strictly of a derivative nature, being produced by their simply spreading from the great primary tide, round points of land and islands. Dr. Whewell did much to establish a map of cotidal lines with the view of extricating the question from those difficulties, and clearing it from the disorder which formerly existed.

It is hardly necessary to notice that, in so far as regards the British coasts, the great tidal wave, after passing over the Atlantic Ocean, splits upon the western coast of Ireland, and proceeds in two courses, one branch forming a wave which passes through the English Channel, and the other through the channels of the Orkney and Shetland Islands, and that these branches meet each other in the North Sea near Yarmouth.

I need scarcely point out how large and beneficial is the influence of these tides on the commerce and wealth of the country, by enabling vessels even of heavy draught to pass inland from the ocean. But in so far as our subject is concerned, viz., "Lighthouses," "Coast Harbours of Refuge," and "Coast-Protection Works," we have principally to consider in what way the tidal current influences such works.

All sea-works are affected beneficially or the reverse by the height to which the tide rises in consequence of the configuration of the land, and on the velocity, due to the same cause, which the tidal currents assume. So long as the tidal wave is passing through great depths in the ocean, the tidal range is comparatively small, but when it enters a bay or firth, and especially a tidal river having converging shores, very great changes are produced, as in the case of the Wye at Chepstow, where the tide has been known to rise 56 feet. This, viewed as a mechanical question, may be accounted for, as stated by Dr. Whewell, on "the principle of the conservation of force. When any quantity of matter is in motion, its motion is capable of carrying every particle of the mass to the height from which it must have fallen to acquire its velocity; but if the motion be employed in raising a smaller quantity of matter, it is capable of raising it to a height proportionally greater. In bays and channels which narrow considerably, the quantity of water raised in the narrow part is less

than in the wider, and thus the rise in such cases is greater."[1] A familiar illustration of this principle is the simple experiment of plunging a funnel with its wide mouth downwards into a vessel of water, when a jet of water springs out of the narrow end of the funnel to a height considerably above the level of the water in the vessel.

As regards the influence of the tides upon wind-waves, it is obvious that the effect of currents running in opposite directions to waves, whether they are merely of an oscillatory nature, or those greater waves of translation which affect the bottom at greater depths, must necessarily result in violent conflict, and give rise to what are called "Races" in England and "Roosts" in Scotland, and which may be witnessed on a small scale in all rivers where the outward current meets the sea and encounters the waves caused by on-shore winds.

In some cases this antagonistic action between the tidal current and the waves increases the height and force of the waves on sea-works and on the shore-line, while in other cases it produces the contrary effect, and acts therefore protectively as would an outer breakwater of masonry.

A well-developed example of the sheltering effect of the Sumburgh "Roost" near Sumburgh Head, the most southern point of the Mainland of Shetland, came particularly under my notice. At one of my visits to that place, I asked the light-keeper to observe particularly during the next heavy gale, whether the waves which reached the shore while the "Roost" was in full action, were not of smaller magnitude than when the action had ceased; and some time after I received the following remarkable testimony on the subject:—

"We had a very severe gale from the south-west yesterday, and being the first gale we have had from that quarter since you were here, I paid particular attention to the state of the sea in the West Voe through the day. By daylight in the morning it was blowing very hard, with a most terribly heavy sea rolling into the West Voe and breaking over the top of the banks, while low-water lasted. But with regard to what you said to me about the tide in the 'Roost' acting as a breakwater to the Voe, your opinion is right, for during the last hours of flood and the first two hours of ebb-tide in particular, a small boat could have gone till within a few yards of the 'Roost' between the Lighthouse and the Horse Island, although the sea was still in the same raging state beyond

[1] Philosophical Transactions, 1833, p. 204.

the 'Roost,' and as far as the eye could reach towards Fair Isle and away to the west."

I may remark that wherever the land projects far from the general coast line, "tidal races" will be found to exist, because the currents which oppose the passage of heavy waves are there intensified. Probably the best illustrations of tidal and wave action are to be found in the Pentland Firth, which may be regarded as the most dangerous navigation of any on the British coast, presenting as it does so many "races" or "roosts." Some writers have alleged that these "roosts" are due to the meeting of contrary currents, while many sailors, on the other hand, believe them to be due to shoal water produced by abrupt vertical changes in the rocky bottom. But the true cause is undoubtedly the large oceanic waves encountering a tidal current running in a direction more or less opposed to their own. For the "roosts" on the west coasts of Orkney and Pentland Firth are known to be worst with ebb-tides and westerly gales, because the Atlantic swell and the current of ebb-tide are opposed; while those again on the east coast are worst with flood-tides and south-easterly swells. The depth of water where the Sumburgh "Roost" runs is not less than 40 fathoms, showing that it is not due to shoal water or to any submerged upstanding rocks.

VELOCITIES OF SOME OF THE MOST NOTABLE "RACES."

| Names of Places. | Authorities. | Velocity at Spring Tides in Statute Miles per Hour. |
|---|---|---|
| Portland Race . . . . . . . | Admiralty Channel Pilot . | 5·75 to 6·9 |
| Open Ocean between Orkney and Shetland . . . . . . . | " North Sea Pilot | 5·76 |
| Hoy Sound, Orkney . . . . . | " " " | 6·90 |
| Holm Sound " . . . . . . | " " " | 6·90 |
| Sumburgh Roost, Shetland . . . | " " " | 8·06 |
| Burger Roost, Orkney . . . . | " " " | 8·06 |
| Hellgate, New York, east current . | Prof. H. Mitchell . . . | 8·50 |
| Doris Mor, Argyllshire . . . | Captain Bedford, R.N. . . | 9·22 |
| Gulf of Corrie Vreckan, Argyllshire | " " . . | 9·83 |
| Roost near Louther, Pentland Firth | Admiralty North Sea Pilot | 10·36 |
| " Swona, " " . | " " " | 10·36 |
| " Pentland Skerries . . | " Survey . . . | 12·20 |

A further proof of the influence of the tide upon the waves is afforded by the experience derived in conducting coast-works, where it has been found that the time at which waves of abnormal height gave rise to damage, was when the tide running near the shore was at or nearly at its greatest velocity. Murdoch Mac-

kenzie, the justly celebrated marine surveyor and hydrographer of last century, remarks, in speaking of the Orkney tides: "that the spring tides acquired a considerable degree of strength in less than one hour after the quiescent state; neap tides are hardly sensible in two hours after still-water; the stream is most rapid commonly between the third and fourth hour of the tide."

In cases where the tide runs close to or near the shore, many examples might be given to show that the damage to harbour-and other works took place after the tide had attained its greatest velocity. It is sufficient to refer to Peterhead harbour, where, at two hours' ebb, after vessels had got aground in the basin, three abnormal waves burst over the seaward pier, knocked down the protecting sea-wall, and washed sixteen persons off the quay into the water. The volume of these waves was such as to set afloat again vessels which had already taken the ground. The contractor's agent stated that, at Alderney breakwater "the heaviest seas and the greatest rush of water over the wall occurred an hour after high-water."

*Criteria of exposed Coasts.*—As the result of many observations, I regard the following as being descriptive of those parts of the coast which are most liable to the impact of unusually heavy waves. (1) The waves are most destructive when they come in at right-angles to the shore line. (2) Their power is increased in proportion as the direction of the main body of the tide approaches to coincidence with the direction of the heaviest swell, and they are probably worst at those headlands on which the tide splits. (3) Where a considerable part of the coast retires, there will be less sea during the strength of the tide, even although the waves come in at right-angles to the shore, because the tide keeps outside, following the direction of the regular trend of the coast; but this will probably not hold true of small re-entrant hollows of the shore. (4) Where the line of exposure and the tide-current are parallel to the coast, if the tide runs in a line very near the shore, as is the case in short narrow channels, where the velocity of the current is increased, there may nevertheless be an unusually heavy sea.

*Level assumed by Mud as a measure of Exposure.*—In the Proceedings of the Royal Society of Edinburgh, vol. iv., p. 200, I referred to a feature which will be found of very considerable value in judging of the exposure of a coast. This is the level below the surface of low water at which mud reposes on the bottom. Though at first sight it might appear unlikely that the disturbance of the sea-level by wind-waves would be propagated to

great depths, there are numerous facts which prove the contrary. Although the absence of mud in any locality proves nothing, because the tide currents may sweep it away, or the geological formation may not produce it, yet its presence seems both a delicate and certain test of the lowest limit to which the disturbance originating at the surface has reached. Thus, as the waves progressively decrease in magnitude in the North Sea between Shetland and the coasts of the Continent, the level of repose of mud progressively rises nearer to the surface, from a depth of 80 or 90 fathoms to only 8 fathoms at the mouth of the Elbe, and to 12 fathoms off the coast of Holland, where ships can take the open beach in nearly all weathers without any protective harbours. If therefore we find, in front of a proposed harbour or coast-work, that mud reposes within a few fathoms of the surface, I believe we have in that fact certain ground for concluding that our works will never be assailed by a very heavy sea.

*Line of maximum Exposure.*—The effect of the action of waves against the shore must obviously vary with the line of maximum exposure, or in other words, the line of the greatest fetch or reach of open sea, which can be easily measured from a chart. The engineer has then to ask himself in what ratio, to the lengthening of this line, the height of the waves may be expected to increase. The result of many experiments on canals and on the Firth of Forth in 1850 and 1852 was that the heights of the waves increased most nearly in the ratio of the square roots of the distances in miles from the windward shore, or when $h$ = the height of the waves in feet from crest to trough, $d$ = distance in miles, and $a$ a coefficient varying with the strength of the wind.

$$h = a\sqrt{d}$$

so that the height of the waves increases in a parabolic curve as they leave the windward shore. For short reaches and very violent squalls a modification of the formula is necessary; but in all ordinary cases and ordinary gales the coefficient in the above formula may be assumed as 1·5.

For shorter distances and violent squalls the following formula is more applicable $h = 1{\cdot}5\sqrt{D} + (2{\cdot}5 - \sqrt[4]{D})$.

It should be carefully noted, however, that there are modifying elements attending the cases of waves approaching the land obliquely; for in consequence of the reduction of the depth, they change their directions and approach the general line of the beach more nearly at right angles, and thus strike with greater force than might be expected. There are also exceptions due to geo-

graphical configuration of the land. In Loch Fyne (Fig. 1), for example, the wind and waves seem to alter their direction with the winding character of the Loch, so that the effective fetch is greater than the length of free water in the Loch would lead one to expect. In other cases the height of the waves is reduced by increased width of water as at Craignure in Mull, shown in Fig. 2, where, during the winter of 1853–54, it was less than the formula indicates.

Another modification in the opposite direction is shown in Fig. 3, where the waves which enter a harbour-mouth at B, though apparently generated by the fetch A B, are also largely due to the fetch C B.

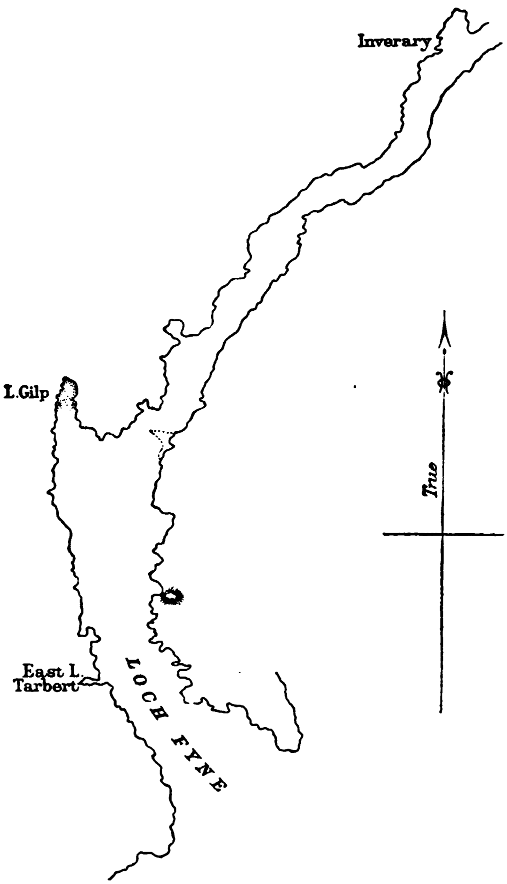
APPROXIMATE HEIGHTS of WAVES DUE to LENGTHS of MAXIMUM FETCH by OBSERVATION and by FORMULAS.

| Place of Observation. | Length of Fetch in Nautical Miles. | Observed Height of Wave. | Height due to Fetch calculated from Formula $h = 1{\cdot}5\sqrt{d}$. | Height due to Fetch calculated from Formula $h = 1{\cdot}5\sqrt{d} + (2{\cdot}5 - \sqrt[4]{d})$. |
|---|---|---|---|---|
| | | Feet. | Feet. | Feet. |
| Scapa Flow | 1·0 | 4·0 | 1·5 | 3·0 |
| Firth of Forth | 1·3 | 1·8 | 1·8 | 3·2 |
| Granton | 2·8 | 4·0 | 2·5 | 3·75 |
| Craignure, Sound of Mull | 3·5 | 2·0 | 2·9 | 3·9 |
| Granton | 6·0 | 4·0 | 3·7 | 4·6 |
| Lough Foyle | 7·5 | 4·0 | 4·1 | 4·96 |
| Clyde | 9·0 | 4·0 | 4·5 | 5·25 |
| Colonsay | 9·0 | 5·0 | 4·5 | 5·25 |
| Dysart | 10·0 | 4·2 | 4·9 | 5·5 |
| Invergordon | 11·0 | 3·5 | 5·0 | 5·7 |
| Lough Foyle | 11·0 | 5·0 | 5·0 | 5·7 |
| Glenluce Bay | 13·5 | 5·5 | 5·6 | 6·1 |
| Anstruther | 24·0 | 6·5 | 7·5 | 7·7 |
| Lake of Geneva, stated by Minard | 30·0 | 8·2 | 8·2 | 8·37 |
| Buckie | 31·0 | 7·0 | 8·4 | 8·5 |
| " | 38·0 | 7·0 | 9·2 | 9·2 |
| " | 38·0 | 8·0 | 9·2 | 9·2 |
| " | 40·0 | 8·0 | 9·55 | 9·5 |
| Macduff | 44·5 | 8·0 | 10·02 | 9·9 |
| " | 45·5 | 10·0 | 10·2 | 10·0 |
| Douglas, Isle of Man | 65·1 | 10·12 | 12·0 | 11·76 |
| Kingstown | 114·0 | 15·0 | 16·0 | 15·25 |
| Sunderland, distance measured from Broken Bank | 165·0 | 15·0 | 19·3 | 18·15 |
| | | 149·82 | 165·57 | 162·68 |
| Mean | | 6·5 | 7·1 | 7·07 |

*Reduction of height of Waves occasioned by shallow Water.*—Another all-important matter is the destruction of the waves, or reduction

of their height, produced by the shallowing of the water near the shore. That this influence, in the case of heavy seas of the kind called waves of translation, is felt at great depths and at great distances from the coast line, is obvious from a statement by

FIG. 1.




Sir George Airy, that heavy ground-swells have been known to break in a depth of 100 fathoms. The great Atlantic seas, before they break upon any but the most exposed portion of our coasts, have probably suffered a considerable diminution of bulk and decrease of velocity. So soon as the lower extremity of the

undulation touches and is reduced by a reef or shoal, the upper extremity, by the process which is known as cresting, loses height in

FIG. 2.

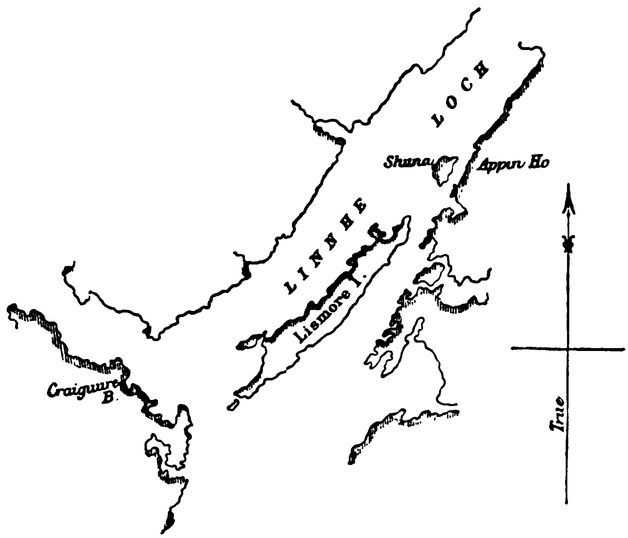
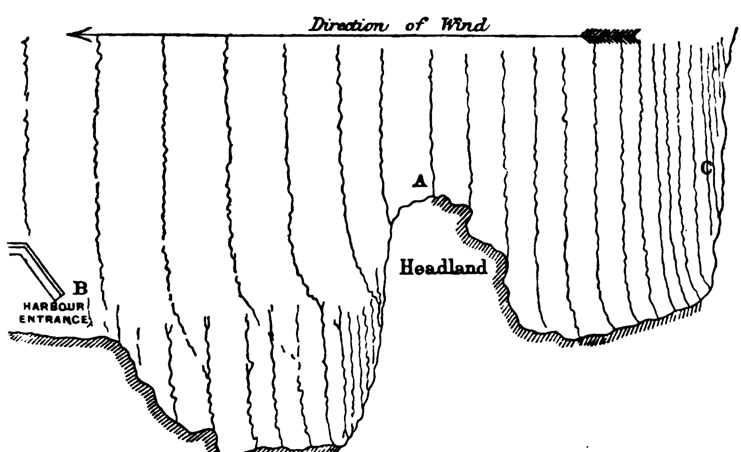



FIG. 3.




proportion. But the wave is not tripped up, and though somewhat lessened and retarded, still continues to rush onward upon the coast.

The actual destruction of the wave takes place in shallower soundings. The late Mr. J. Scott Russell, who has conferred so many obligations on the maritime engineer, found that waves break when they pass into water of the same depth as their height, but there are exceptions to this law. In 1870 I noticed at Scarborough, that waves broke when the depth of water was double the height of the wave, the depth being measured below the mean level, and the height from hollow to crest.

*Force of the Waves.*—By means of a marine dynamometer, the force of the waves was ascertained at Skerryvore Lighthouse in the Atlantic, when during a heavy westerly gale I found that a force equal to nearly 3 tons per square foot was registered; while at Dunbar, where the observations were continued for a much longer period, a force of $3\frac{1}{2}$ tons was registered on more than one occasion.

## Coast-Works.

The most seaward and most exposed of sea-works are generally lighthouses erected on outlying rocks in the sea.

As regards the design of this class of sea-works, much as Smeaton's tower has been appreciated, I am distinctly of opinion that, in one very important feature, namely the outline, the former tower by Rudyerd is decidedly superior for a small rock such as the Eddystone. It is long since I expressed that opinion, and subsequent experience has only tended to corroborate it. I have given general rules in my book on "Lighthouse Construction and Illumination," 1881, p. 28 *et seq.*, which I think will be found useful as a guide to selecting the safest modes of construction.

The profiles shown in Figs. 4, 5 and 6 are suitable in situations where the rock is either soft, hard, or of small dimensions respectively.

*Modifying influence of the configuration of Rocks on breaking Waves.*—I am satisfied of the great influence exerted by the shape and height of the rocks on which lighthouse towers are built; and I feel bound to take this opportunity of again expressing my conviction that Smeaton's tower should not be regarded as a safe model for imitation on rocks which are exposed to a heavy sea. Nothing less can be deduced from the remarkable fact that the level above the sea at which fourteen blocks of 2 tons each, set and fixed by joggles, dovetails, and cement, were dislodged and swept away by a summer gale at Dhu Heartach, is the same as that at which the thin crown-glass panes of Winstanley's lantern remained unbroken through the storms of a whole winter. It was

on this principle, and in consequence of this experience, that a change was made in the original design of the Dhu Heartach, and the solid part carried up to the same level above high water as the lantern in Smeaton's tower.

The very remarkable cases of wave-action exerted at high levels

FIG. 4.

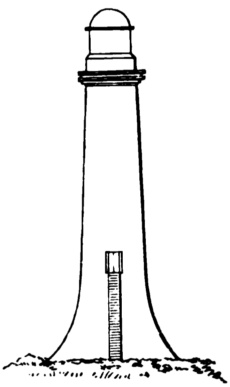


FIG. 5.

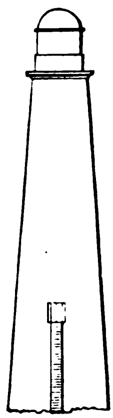
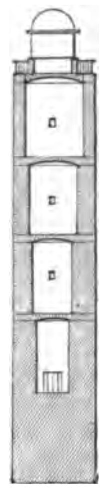


FIG. 6.



on the rocks at Whalsey, Unst, and Fastnet, are further corroborative of this view.

To decide upon the probable exposure of any rock, and the height of the dangerous impact of waves above high water, many elements have to be considered; the height of the waves, the height and configuration of the rock above and below low water, and the depth and configuration of the bottom of the sea; and it is unfortunately necessary to add that the influence and relations of these elements have not as yet been sufficiently studied. What may be the effect, whether as shield or conductor, of a given height of rock upon a given height of wave; what may be the effect of such a deep track in the bottom of the sea as that observed by Mr. D. A. Stevenson near Dhu Heartach; or how much would depend on the direction of such a track, or on the level at which the rock is steep in relation to the height of tide most favourable to heavy seas—are all questions of great importance, still unsolved and well worthy of the attention of the engineer. A rock like Dhu Heartach certainly acts at once as a breakwater against the smaller class of waves, but a dangerous conductor to the heavier.

Again, in some observations I made at Skerryvore in 1845, interesting differences were found to exist in wave-force at different levels.

WAVE-FORCES EXERTED at DIFFERENT LEVELS on an EXPOSED PART of the SKERRYVORE ROCK.

| Date. 1845. | Remarks. | No. of Dynamometer. | Pressure in lbs. per square foot. |
|---|---|---|---|
| Jan. 7. | Heavy sea . . . . . . . . | No. I. | 1,714 |
| „ 7. | „ „ . . . . . . . . | No. II. | 4,182 |
| „ 12. | Very heavy swell . . . . . | No. I. | 2,856 |
| „ 12. | „ „ . . . . . . . | No. II. | 5,032 |
| „ 16. | Heavy ground swell . . . . . | No. I. | 2,856 |
| „ 16. | „ „ . . . . . . | No. II. | 4,752 |
| „ 22. | A good deal of sea . . . . . | No. I. | 2,856 |
| „ 22. | „ „ . . . . . . | No. II. | 5,323 |
| „ 28. | Heavy ground swell . . . . . | No. I. | 2,627 |
| „ 28. | „ „ . . . . . . | No. II. | 4,562 |
| Feb. 5. | Fresh gales . . . . . . . . | No. I. | 856 |
| „ 5. | „ „ . . . . . . . . | No. II. | 3,042 |
| „ 21. | „ „ . . . . . . . . | No. I. | 1,827 |
| „ 21. | „ „ . . . . . . . . | No. II. | 3,422 |
| „ 24. | Fresh breezes . . . . . . . | No. I. | 1,256 |
| „ 24. | „ „ . . . . . . . . | No. II. | 3,802 |
| Mar. 9. | Ground swell . . . . . . . . | No. I. | 1,256 |
| „ 9. | Waves supposed to be about 10 feet high . . . . . . . . | No. II. | 3,041 |
| „ 11. | Short sea . . . . . . . . . | No. I. | 1,028 |
| „ 24. | Heavy sea . . . . . . . . . | No. I. | 2,281 |
| „ 24. | Waves supposed to be about 20 feet high . . . . . . . . | No. II. | 4,562 |
| „ 26. | Swell . . . . . . . . . . | No. I. | 1,256 |
| „ 26. | Waves about 6 feet high. . . . | No. II. | 3,041 |
| „ 29. | Strong gale with heavy sea, the highest waves supposed to be 20 feet | No. I. | 2,856 |
| „ 29. | and the spray rose about 70 feet . | No. II. | 6,083 |

Two dynamometers were affixed to the rock; No. I. several feet lower and about 40 feet seaward of No. II.; and, as will be seen in the Table, the force registered at No. II. was generally about twice as great as at No. I. It seems to me that it would be of great value, before designing lighthouse-towers, to take what may be called dynamometric sections, such as this one taken at Skerryvore, and to examine the results in relation to the varying profile of the rock, and, if possible, to different stages of the tide. Such sections, it need hardly be observed, will never form a perfect guide in the particular instance, for we shall no sooner have obtained our observations, than we shall begin to change the profile of the rock by the addition of the tower itself, and thus to alter the very conditions of what we have been observing. But it is only in this way that I can foresee any chance of our advancing

towards sure knowledge of the general law; and I embrace this opportunity of suggesting this course of observation to the younger members of the Institution.

*Harbours of Refuge.*—The next class of works, reckoned seawards on approaching the coast, are those large structures to which the name of Harbours of Refuge is given. They are distinguished from tidal harbours by the generally greater depth of water which they require to possess, in order to fulfil the objects for which they are designed, while the area which they enclose must also be larger. The requisites are shelter during storms, good holding-ground, and safe access at all times of the tide and in all states of the weather. A breakwater, though a passive, is yet a real agent, having work to do. Many thousand tons of water are raised and maintained above sea-level by wind-waves, and these waves must either be suddenly stopped, or as suddenly reversed in direction, or else more slowly destroyed within a given space. This is the work assigned to the breakwater, and there are two ways in which it can be done. One way is by means of a plumb wall, which alters the direction of the moving water by causing it to ascend vertically above the parapet of the wall, and then allowing it to fall vertically again, so that the waves are finally reflected and sent back seawards. The other method is to arrest the undulations by a long sloping wall, so as to give room for the mass of the waves to fall down and destroy themselves upon the surface; but if the slope be not sufficiently long to enable the waves thus fully to destroy themselves, they will, though reduced in height, pursue their original direction, pass over the top of the breakwater, and thus disturb the tranquillity of the harbour. In such a case as this, therefore, the breakwater has failed to do its full share of work, and the necessary amount of shelter has not been produced.

*Best position for Harbours of Refuge.*—Opinions have been recently expressed that a harbour of refuge should be placed in a re-entrant part of the coast, and never at any part which is salient. Now it is of great importance that such a question as this should be fully discussed, as the result must materially affect the interests of commerce and shipping. Various conditions statistical, geographical, and local should be considered in this question.

(1) *Statistical.*—So far from being necessarily placed in the neighbourhood where most shipwrecks have occurred, as has been alleged, or as an escape for vessels locally embayed, the harbours of refuge should, in my opinion, be situated as near as possible to the normal track of shipping. Thus, on the occurrence of a gale,

a refuge will be ready in a position which can be quickly and safely approached by the greatest possible number of vessels, both large and small.

(2) *Geographical.*—The true situation for a harbour of refuge is rather upon a salient than on an embayed part of the line of coast, because: (i.) as I have already stated, a salient part of the coast will lie nearer to the line of the general passing trade than a re-entrant part; and (ii.) Vessels seeking a haven and failing to make it, will not find themselves embayed, but be still well to windward, and have sea-room to bear away for some more distant haven on either hand. There is indeed a sense in which a harbour of refuge in the bottom of a bight may be regarded as a source of danger instead of a source of safety. Cardigan Bay in Wales, for example, is just such a place as might perhaps be selected. But though a harbour in Cardigan Bay might in certain exceptional cases do good, it would be dearly purchased if the presence of the harbour tempted masters to leave the track of safety and unnecessarily to embay themselves. It will, I think, be generally admitted, that if, from fog or snow-showers coming on, a vessel failed to pick up the position of the harbour in the bay, there would be hardly a chance of her escaping shipwreck. A harbour of refuge, on the principle asserted, is either kill or cure, for it offers but one chance to the distressed vessel, which she must seek at the cost of embayment; but a harbour of refuge on a salient part of the coast offers a chance of shelter without necessarily compromising the safety of the ship in case she fails to make it.

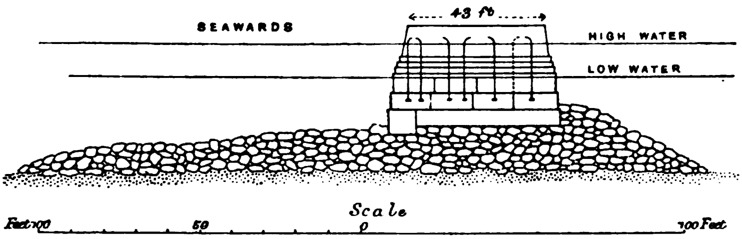
(3) *The local conditions pointing to the Proper Situation for a Harbour of Refuge are:* (i.) The inclosure of the greatest area of sufficiently deep water for the least extent of breakwater to be constructed. (ii.) The quality of the holding-ground in the anchorage thus to be sheltered. (iii.) The proximity of suitable material for the construction of the breakwater.

*Best Mode of Construction of a Harbour of Refuge.*—With reference to the best mode of construction for a harbour of refuge in an exposed situation, there will always be considerable differences of opinion among members of the profession. I shall simply state the form of construction which, on the whole, I consider to be best in situations where the place is fully exposed to the heaviest class of waves.

A very obvious and very important point regarding the stability of such a structure as a breakwater has reference to the depth below low water, at which the waves cease to exert any considerable

impact upon the materials on which the superstructure rests. Information of great importance was derived from the history of the Wick breakwater, for which my firm were engineers, and which, so far as I have been able to ascertain, was subjected to the heaviest waves that have ever assailed masonry. It is sufficient to state that the results which I have obtained, at many different parts of the coast, by means of the marine dynamometer already referred to, have been far exceeded by the effects produced by the very anomalous waves which assailed the harbour works of Wick, where the contractor's staging, though consisting of greenheart timber, was found quite unequal to resist the stroke of the sea, and where the heavy rubble which formed the substratum of the work was

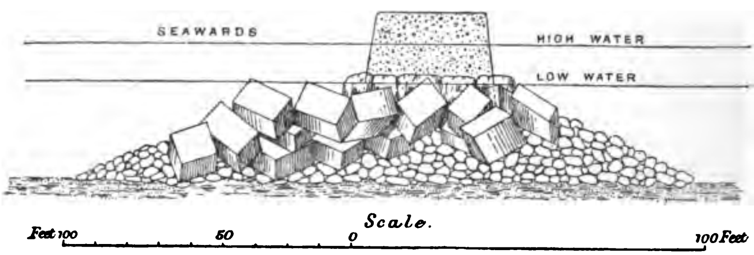
FIG. 7.




moved at a depth of about 18 feet below low-water. In 1872, a huge monolithic block of concrete, weighing in all 1,350 tons, was removed bodily out of its position, and carried to the lee of the breakwater. Extraordinary as this may appear, it was surpassed in 1873, when another concrete mass which had been substituted for the one that was moved, was in like manner carried away, though it contained 1,500 cubic yards of cement and rubble, the weight of which was about 2,600 tons. Yet it is remarkable that after the last damage which took place to the breakwater, when we thought of removing the foundation courses, which were set on edge, we found it impossible to do so, owing to their being so firmly imbedded in the rubble base; no part of the foundation of the breakwater was ever moved, nor any of the rubble base ever disturbed, at a lower level than 18 feet under the water. *I am therefore of opinion that a level of from* 18 *to* 20 *feet below low-water level may be safely assumed as that of practical stability.* In Fig. 7, showing a section of the end of Wick breakwater, it will be noticed that the bay consists of a sandy bottom, and it is, as I have said, fully exposed to the swell of the North Sea. I conceive that the safest and most economic profile of construction would be as

shown in Fig. 8, a mass consisting of rubble extending from the bottom to within 20 feet of low-water; when the base had been brought up to this level, blocks of concrete weighing from 100 to 200 tons should be deposited on the top, and outer or seaward surface of the rubble base, till they came above low-water level. Betwixt the spaces at the top of these blocks, bags of concrete should be placed, so as to form a level platform above low-water level. Upon this a solid mass of continuously-built concrete should extend from end to end of the breakwater, which should be not less than 10 feet above high water, and about 45 feet in breadth. I hold that a structure designed on these principles would resist the force of the sea in any situation, provided the sea slope were

FIG. 8.




of sufficient extent. This was the design proposed for the Peterhead Refuge-Harbour, and which was approved of by the Committee on Convict Labour.[1]

*Mattress Breakwaters, or Training Walls constructed of Fascines.*—There are in many parts of the world bays and arms of the sea of so shoal a character as to cause the waves to break several miles off the shore, but where difficulties of another kind arise from the soft nature of the subsoil; so that although there is no very violent sea to be encountered, yet breakwaters of concrete or masonry are unsuitable, owing to this softness of the bottom; for the waves, reduced though they be, are still able to produce sufficient reaction from the outer face of the breakwaters to plough up the bottom. In order to meet these difficulties, structures called mattresses, which possess peculiar characteristics, have been resorted to in various parts of the world, particularly in Holland and America,

[1] Report of the Sub-Committee appointed to investigate the question of the most suitable place for a Harbour of Refuge on the East Coast of Scotland. 1884. p. 8.

where they have been found very suitable. In the well-known case of the River Mississippi, for example, Mr. Eads most successfully removed the bar by means of mattresses. The requisites for such structures are that they should be of small specific gravity and of open texture. They must also project but little above the bottom, so as to avoid coming within the direct influence of the breaking action of the waves, and thus to cause reaction, which would endanger the foundations. They must, in short, operate strictly as submarine breakwaters in stopping the action of the waves at the bottom, while they also possess a certain amount of pliancy to enable them to adapt themselves to considerable variations in the level of the bottom, so as to deflect the under-water currents.

*Commercial Harbours.*—It would far exceed the limits of this lecture were I to attempt to take up the subject of commercial harbours and the like. It may, however, be right to define the great object which must be kept in view in carrying out works of that nature; and that object is to produce a harbour which may easily be taken in rough and stormy weather, without endangering the tranquillity of the internal area; for it is the combination of an easy and safe entrance and exit, with what sailors call a good "loose," and a smooth interior, which alone constitutes a good harbour.

It must further be remembered that a bad result may ensue from devoting an exclusive, or too great an amount of attention to one branch of the subject, however desirable the securing of that branch may be in itself; such, for example, as obtaining deep water at the expense of still more important conditions, viz., suitable protecting works, and sufficient internal area. The disregard of a due proportion between the internal area and the depth of a harbour has in many instances produced harbours which cannot be said to deserve that name. In order to show how the tranquillity of a harbour may be affected, and how cautious, therefore, the engineer should be in changing the existing physical relation, I have thought it right to refer to some of the many works which may prove injurious.

*Causes of insufficient reduction of height of Waves.*—The causes of insufficient reduction of height of waves after entering a sheltered basin may be stated to be too little breadth in relation to width of entrance, or adequate area in relation to the magnitude of the waves outside; also the surrounding of the internal area with vertical walls, and the absence of sufficient length of spending beach to destroy the waves and prevent recoil.

A formula for calculating the reductive power of harbours will be found in my book on Harbour Construction.[1]

*Commercial value of depth of Water.*—I may state that I have found that the commercial value of harbours or rivers increases as the cubes of the depth of water, although no stated rule can be regarded as more than generally true. The following formula is designed to apply to this subject when $d$ represents the draught of a vessel in feet; $t$, the burden in tons; $a$, a constant depending on build,

$$t = \frac{d^3}{a} \text{ and } d = \sqrt[3]{a \times t}.$$

*Coast-Protection Works.*—The last branch of the subject which has been assigned me refers to works which are furthest from the action of the sea, or those for the protection of the land itself.

The physical configuration of the coast-line affords, as every one knows, a series of the most varied vertical and horizontal profiles. It is generally owing to the effects of atmospheric action, combined with wave-action, that such phenomena are due. The two parts of the British coast, which best illustrate the particular case of moving of sand and shingle, are those of the English Channel and the Moray Firth. I have always been of opinion, I may remark in passing, that the action of tidal-currents has nothing to do with the throwing up of shingle on any coast, and the valuable Paper of Sir John Coode[2] should, I think, set this matter fully at rest. The breaking of waves at right-angles to the coast is quite sufficient to account for the heaping up of shingle between high- and low-water mark, while the oblique action of the waves sufficiently accounts for the travelling movement of the shingle in the same direction as the heaviest winds. But the cause of the formation of bays or creeks must generally be sought for in the unequal hardness of the different members of the geological formation which confront the sea, and which form a remarkable contrast to the rocky strata or igneous class of rocks, which continue to maintain their integrity from their greater hardness.

The general slope of a fragmentary beach must depend upon the size and nature of the particles and the force of the sea. The great object, therefore, in artificial works of protection, is to design the profile of the wall, so as to alter as little as possible the symmetry of the beach. Where isolated rocks or large boulders

[1] The Design and Construction of Harbours. p. 185.
[2] Minutes of Proceedings Inst. C.E. vol. xii. p. 521.

are left projecting above the surface of a sandy shore, there will generally be formed around them hollows corresponding in depth and form to the kind of obstruction which the rocks present. The principal point in the design of artificial works of protection is, therefore, to avoid great and sudden obstructions to the movement of the water. The best form which could be adopted in any situation would, of course, be the contour of the beach itself; but this would answer no possible purpose; and as the wall is to consist of heavy blocks of stone instead of minute particles of sand, it is clear that a much steeper slope may be adopted than that which we may call the profile of conservancy of the shore, provided the lower part of the slope be flattened out so as to meet the sand at a low angle. The action of a bulwark is to arrest the waves before they reach the general high-water mark, and to change the horizontal motion of the fluid particles to the vertical plane, or to compel the waves to destroy themselves on an artificial beach consisting of heavy stones. To prevent underwashing, the two following requisites should therefore be as far as possible secured:—First, the foundation courses of the wall should rise at a very small angle with the beach, so that their top surfaces may form a continuous curve, with the profile of conservation of that portion of the beach out of which the wall springs. Secondly, the outline of the wall should be such as to allow the wave to pass onwards without any sudden check till it has reached the strongest part of the wall, which should be placed as far from the foundation as possible.

*Loose rubble a good protection for the foundations of Bulwarks for protecting Land from the Sea.*—Loose blocks of angular rubble furnish, in most cases, the best possible security when the soil is soft or friable, for the waves are swallowed up by the interstices. A regular sloping sea wall or bulwark, with a smooth surface, becomes, when the soil is soft, a double-edged sword in working its own destruction at top and bottom; for it transfers the duty of destroying the waves from the masonry to the unprotected soil at the top, and to the loose sand or gravel at the bottom of the wall. While the foundations are underwashed by the reaction upon the soft bottom, the upper parts of the masonry are deprived of support by the falling water and spray, which are led up by the masonry, and soon wash away the soil at the top.

*Vertical Walls.*—For the reasons which have been stated, it is plain that a vertical wall is in most cases unsuitable for a sandy beach. Instead of altering the direction of the wave at a distance from its foundation, the whole change is produced at that

very point; and, unless the wall be founded at a considerable depth, its destruction is all but certain. Where the materials are costly, but admit of being easily dressed, I am disposed to think that a horizontal, or nearly horizontal, apron or platform of timber or masonry, connected with a vertical wall by a quadrant of a circle of sufficient radius, may be found answerable. Such a form will prevent to a considerable extent the danger of reaction, by causing the alteration in the direction of the wave to take place at that part where the wall is strongest, and which is also at the greatest possible distance from the toe or curb-course. If the materials are abundant, and of a rough nature, a cycloidal wall with vertical and horizontal tangents, somewhat similar to that erected at Trinity, near Edinburgh, may be adopted with advan-

FIG. 9.

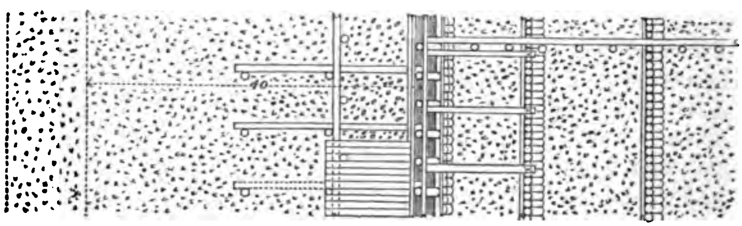
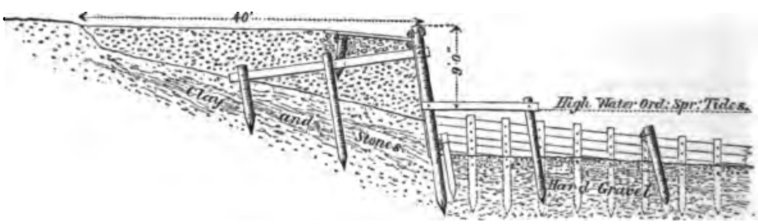



FIG. 10.




tage. But a very serious objection to all forms of curved walls, unless the radius be large, is the weakness which results from the use of wedge-shaped face stones. The impact of the sea on materials of that form may be compared to a blow directed upwards against the intrados of a stone arch—the direction of all others in which the voussoirs are most easily dislocated. This action can only be successfully resisted by very careful workmanship in the dressing and the setting of the backing. Another objection, applicable to all except tideless seas, such as the Mediterranean, arises from the varying level of the surface of the water; for that

profile which may be best at one time of the tide cannot be equally suitable at another.

*Works for protecting land in open Estuaries.*—In other cases in estuaries more open to the sea, works of a stronger kind are required. Figs. 9 and 10 are a plan and section of a protection which was adopted on a line of shore composed of shingle. Jetties projecting from the shore had at first been used to collect the shingle, but in heavy seas the waves were led along the jetties, and had a hurtful effect at their roots where they joined the beach. A continuous line of piling and planking was accordingly adopted, combined with occasional jetties, and this has proved very successful. In proof of this, it has been found that wherever the upright piling and planking have been formed, there was no influx of anything beyond spray upon the adjoining land, but that at all other parts of the coast (which is about 6 miles in length), where the face of the beach is sloping, the water passed freely over in considerable depth, carrying drift timber far into the fields, and in some places heavy shingle to the depth of 2 feet. The problem to be solved was to oppose an obstacle which should throw back the sea; and the upright face, from which the heavy portion of the sea recoils, was found to do this better than the sloping face. In order to encourage the collection of shingle, a second line of longitudinal piling was, at some places, formed in front, and parallel to the main line of defence; and the works now described have been found a very effective defence on a line of shingle beach, exposed to a considerable sea, on the shores of the Bristol Channel.

In designing all such works, however, the engineer must be guided by the formation and exposure of the shores, the kind of materials most easily available, and above all, the value of the property endangered, as every engineer must know by experience that in some situations protection can only be secured at a cost out of all proportion to the benefit which it would confer.

The notable difference between the subject to which my attention has been directed by the Council, as compared with the other lectures, is the extreme want of exactness which characterises the whole subject. In no other branch of engineering is there so great a prevalence of what may be called "rule of thumb." Indeed, hardly any attempt has been made to obtain observations, reducible to a formula, by which numerical results can be calculated as to the force of waves; the height of waves, in relation to the depth of water in which they move; the reductive power of harbours, by which the waves after

entrance are diminished in height; the shelter due to protecting breakwaters, and the like. I would strongly counsel young engineers to do their best to supply these *desiderata*. Here is a field where they may do good service to the profession and in the interests of mankind. Here is a branch of engineering where we are still in want of facts, and to a far greater degree in want of the means of scientific calculation. No one knows better than myself the difficulty of the task; for I have had a large experience, and have been too often baffled in my best endeavours to obtain coefficients. But we must not look to difficulty; we must look to utility; and I see no branch where the patience, the ingenuity and the scientific accuracy of observers will be likely to produce more useful results than the one to which I refer. Lastly, I would say a word of welcome to a new book: Mr. Vernon-Harcourt's "Harbours and Docks." It is (particularly on the historical side) a treasury of facts, and forms a large addition to the historical library of the marine engineer.

Sir Frederick Bramwell, President, asked for a hearty vote of thanks which might be conveyed to Mr. Stevenson, to show that his labours had been appreciated by the members, although they had not had the benefit of his presence. Mr. Stevenson himself had revealed the fact that he took up the lecture at very short notice, when Sir John Coode was by professional engagements compelled to leave England, and therefore was unable to deliver this lecture which had originally been assigned to him. Their thanks were therefore doubly due to Mr. Stevenson.

Mr. Giles, M.P., had much pleasure in seconding this cordial vote of thanks to Mr. Stevenson. He was sure they all regretted very much his absence. Perhaps no engineer had had greater experience, more particularly in the wild waves on the coast of Scotland, than Mr. Stevenson, and he was better qualified, perhaps, than most marine engineers to speak upon the effects of water-pressure upon harbour-construction. At the same time, he thought Mr. Stevenson had been a little hard on the profession generally when he said that most harbour-constructions were designed, not upon scientific principles, but simply by rule of thumb. It was very true that engineers ought all to be guided by science in the constructions which were subject to great sea-exposure; but notwithstanding all the science that might be brought to bear upon the construction of harbours, they were still guided to a certain extent by the experience they had gained in their constructions.

The vote of thanks was unanimously agreed to.

7 May, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

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## "Forms of Ships."

By Sir EDWARD J. REED, K.C.B., F.R.S., M.P., M. Inst. C.E.

As it was the object of the Council in instituting these Thursday lectures to bring before the Institution not such mere summaries of subjects as could be readily compiled from books, but rather such discourses as would embody the results of the personal investigations and experiences of those who were charged with their preparation, I need offer no apology for the form which I propose to give to the present Lecture. It will not be either possible or desirable to avoid reference to some well-known principles and familiar facts, or to keep out of view the experiments of others; but these will be referred to only for the purpose of facilitating the discussion of the forms of ships from the points of view from which I intend to regard the subject.

As I desire this evening, in the first place, to bring into prominence the doctrine—as yet but imperfectly realized—that the form of a ship should be very largely influenced by the weight of the materials which enter into its construction, and vary in amount with the extent of the ship's surface, I will first ask my audience to consider for a few moments one of the simplest cases of a floating body adapted for propulsion which can well be imagined. This is the case of a body formed, as we may suppose it to be, out of a smooth sea, by the solidification—as for example, by freezing —of an envelope of water enclosing within its outer surface the required displacement of the proposed ship. It is obvious that, if we simply desire a vessel of a given displacement, say for instance, one of 6,000 tons, we shall have an infinity of forms to select from. We may, for example, imagine our vessel to be excessively long and narrow, say a mile long, a couple of feet wide, and twenty feet deep; or we may imagine her to be of the same depth, but of a circular form 120 feet in diameter; but we may also, and with much more regard to ordinary experience, imagine her of dimensions and form very different from, and lying some-

where between, these extreme cases. From the most recently established, and now generally accepted, laws of fluid-resistance, we may at once infer that the ice-ship a mile long, with any ordinary roughness of the ice-surface, would, if moved through the water at high speed, be subject to the resistance of enormous surface-friction while performing next to no wave-making and eddy-making work; we may as readily infer that the circular ice-ship of 120 feet diameter would, at like speed, be subjected to enormous resistances due to wave-making and eddy-making, while her surface-friction would be comparatively small. Between the extreme forms suggested, there will be an indefinite number of forms of equal displacement, but of varying dimensions, and it is but reasonable to suppose that among these there will be one in which the proportions of the elements of resistance just adverted to are so adjusted that the aggregate resistance will be the least possible for the speed to be attained. What this "form of least resistance" in water at that speed may be, it is no part of my present intention to inquire, for, as will presently appear, it is not a form suitable for practical adoption in ships. There was a time, it is true, when the search for an abstract "form of least resistance" was a familiar pursuit of the designers of ships; and it is not impossible that I might have myself regarded it with more respect, but for the circumstance that I have had much to do with the designing of armour-plated vessels of war, and that is a branch of naval construction of much too concrete and ponderous a character to admit of any dalliance with abstract or fancy forms.

Let us, nevertheless, suppose for a moment that, either by an act of supreme science, or by a freak of fortune, we have secured that form and those dimensions for our ice-ship which, while giving us our displacement of 6000 tons, admits of the desired speed being attained with the least resistance, and, therefore, with the minimum amount of propelling power. The thickness of our ice-skin may be anything we please (neglecting the difference of specific gravity in ice and water), without at all disturbing the conditions of our problem; we will take it to be one inch thick. But now let us imagine that we have to pass from this fragile ice-hull to a hull of steel, and it is obvious that our conditions of equilibrium will disappear, and the excess of weight of the steel hull, as compared with the hull of ice, will sink the ship. In order to induce it to float, we must hasten to depart from the form of least resistance, and bend our steel skin into a different form, which must be such as to embrace within its outer surface a displacement equal to the weight of the steel hull, plus the

weight of the contained water, which weight of contained water we will suppose to remain unaltered, and to constitute the load carried by the ship. The new form of the ship must clearly be such as will comprise within its outer surface a larger volume than before, and this practically involves a decrease of length and an increase of breadth, if the depth remain the same.

Similarly, if our steel ship were required to be of a greater uniform thickness, it is plain that we should then be driven to a still shorter and broader hull, and so on until we came to a circular ship. That form once reached, and the vessel with a given thickness of skin and its given load of water on board, just floating, it is obvious that we should have been driven very far indeed from the form of least resistance, and should have been so driven solely by successive increases of thickness and weight of hull.

Thus far we have considered the variations of form imposed upon us by these increases in thickness and weight of hull, subject only to the necessity of floating a given load; and it is pretty obvious that at every step we have increased the resistance of the hull to forward motion, and have reduced the speed which would be imparted to the ship by the exertion of a given propelling force, simultaneously increasing, of course, the amount of force requisite if the original speed is to be sustained throughout. If we now introduce the idea of the ship carrying in each case its own propelling machinery as part of its load, it is obvious that if we presume the speed to have been always the same, the weight of that machinery must have been increased at each step of the process, and the remaining available load therefore proportionately reduced. A little consideration will show that, in keeping up that speed, the whole load-carrying power of the hull will have been absorbed by the machinery long before the circular form is reached, after which, as the thickness of the hull is increased, the speed must undergo continual reduction.

The foregoing elementary mode of viewing the subject is in itself quite sufficient to establish the fact that there is no such thing as an abstract best form for a ship, apart from the thickness and weight of its structure. In order to further illustrate this, let us consider a specific problem; the following, for example: Let it be our object to produce a ship of the thickest material possible within reasonable limits of size, which shall steam at 14 knots, carrying a deadweight of 1,000 tons, and a coal-supply equal to twice the weight of the machinery requisite to ensure the given speed; and let us assume that the weight of the machinery is to

be 2½ cwt. per indicated HP., and that the draught of water is 24 feet in all cases. In order to obtain at first some general guidance as to the form and proportions which it is desirable to adopt, we will take the Admiralty displacement formula,

$$\text{Constant} = \frac{\text{Speed}^3 \times \text{Displacement}^{\frac{2}{3}}}{\text{Ind. HP.}}$$

as sufficiently approximate to the truth for our purpose, and select from the records of ships which have been tried, the constants of performance of a fine-lined ship, a medium ship, and a very full ship, these being respectively, say, 230, 160, and 80. A ship must be of very full form indeed to have so low a constant as 80 at 14 knots speed, but I take it as an extreme case, and for the sake of obtaining a contrast. We will further assume for our purpose—as the object in view is not quantitative, but only illustrative—that the same constant holds in each case for all sizes of ships of similar form. The following Table gives the results of calculations made upon ships of ordinary forms, the whole weight of hull in each case being represented in inches of uniform thickness of shell-plating. For the sake of simplicity, I have dealt with the under-water part of the ship only, and have assumed that the weight of the hull above water is so light as to be left out of consideration.

TABLE I.—SPEED 14 KNOTS.

| Thickness of Hull in Inches. | Fine Ship. $\frac{S^3 D^{\frac{2}{3}}}{\text{I. HP.}} = 230.$ Displacement. | Medium Ship. $\frac{S^3 D^{\frac{2}{3}}}{\text{I. HP.}} = 160.$ Displacement. | Full Ship. $\frac{S^3 D^{\frac{2}{3}}}{\text{I. HP.}} = 80.$ Displacement. |
|---|---|---|---|
| | Tons. | Tons. | Tons. |
| 5 | 3,300 | 3,600 | 8,500 |
| 6 | 3,900 | 4,100 | 9,700 |
| 7 | 4,700 | 4,800 | 11,100 |
| 8 | 5,700 | 5,600 | 13,000 |
| 9 | 7,200 | 6,600 | 15,200 |
| 10 | 9,200 | 7,800 | 18,000 |
| 11 | 12,400 | 9,400 | 21,500 |
| 12 | 17,200 | 11,400 | 26,000 |
| 13 | 24,000 | 14,000 | 31,400 |
| 14 | 37,300 | 17,400 | 37,800 |
| 15 | 63,700 | 22,000 | 46,500 |

These results are shown graphically in Figs. 1 and 2, Plate 6, of which Fig. 2 is part of Fig. 1, with the scale of displacement increased. From the Table and diagrams we see at once that, throughout the whole range of the thicknesses from 8 inches upwards, the ship of medium form is smaller, and should therefore be preferred to either the fine or the full ship, if size and first-cost alone had to be considered. But as it is obvious that the shorter and smaller ship will, for any given displacement, require greater steam-power than the finer and larger ship, the question will arise, at what point will the ships present equal advantages. In determining this, we clearly shall have to decide for ourselves where to draw the line between a saving in first-cost and a saving in fuel-expenditure. It is unnecessary to attempt this here; the more so as we shall, as the weight of the hull increases, sooner or later reach a point at which the short bluff ship will be driven at the given speed with no more power than the long fine ship requires, owing to the former being of so much less size than the latter. For the moment, however, I wish to neglect the question of steam-power and fuel-expenditure, and point out the relation that exists between the different types of ship as regards the size requisite for constructing hulls of equal mean thickness, and capable of steaming at the 14 knots with the given load. As compared with the fine ship, the medium ship is inferior in this respect at thicknesses below 7 inches, and the fine-lined ship therefore shows to advantage at that end of the scale, as was to be expected. They are about equal for a 7-inch hull, but for hulls above 7 inches the advantage is with the medium ship, and increases rapidly with further increase of thickness. For a hull 12 inches thick, while the fine ship requires a tonnage (displacement) of 17,200, in order to accomplish the object, and the full ship requires about 26,000 tons, the medium ship fulfils the condition with 11,400 tons. Were a hull of 14 inches mean thickness required, the medium ship would satisfy the condition on less than 18,000 tons, while both the fine and the full ship would each require to be of more than 37,000 tons, or more than double the size. At about this tonnage the ship of very bad form (with constant of 80 only) has overtaken the ship of fine form, and now begins to gain an ever-increasing advantage over her, the amount of steam-power required being still left out of consideration. It is unnecessary to pursue the comparison further, it being completely manifest that a fine form of ship which is desirable when the hull is lightly constructed, may be a very bad form indeed for a very heavily-built ship; and *vice versâ*. It is equally plain that,

while the introduction of steel should tend to increase the fineness of the lines of properly-designed vessels, the use of armour should have a contrary result. The practical importance of this principle has been illustrated in the Royal Navy by the substitution, as will presently be seen, of the "Bellerophon," "Hercules," "Sultan," and other succeeding short ironclads, for the long fine-lined ships of the "Agincourt" type which preceded them.

It now becomes necessary to take into consideration the amount of power required for propelling the respective types of ships. It would not be a very judicious thing in most cases to save moderately in the size and cost of the ship itself, when that saving would entail a large and more or less continuous increase in the cost of the fuel consumed. This consideration is not of such great importance in the case of war-ships, which are but very seldom driven at their full speed; but it is of supreme importance in all ships which are intended to sustain their full speeds for long periods. Keeping this in view, let us now see how the respective types of ships, chosen for our illustrations, are related to each other. The accompanying Table II., shows the relation between the thicknesses of hull, and the horse-power required for driving the corresponding ships at 14 knots. Of course no Table is necessary to show us that for any given displacement the steam-power required for propulsion at the given speed will be in inverse proportion to their constants. For example, the medium ship will only require, per ton of displacement, one-half the steam-power of the full ship, because her constant is double that of the latter. Similarly the horse-power requisite for the full ship will be to that required for the fine ship as 230 : 80, or nearly three times as much. But employing the Tables for our purpose, we shall see that within the limits of the Tables, the full ship never becomes unquestionably entitled to preference, because, although for a 15-inch hull, she would require to be of only 46,500 tons displacement, against the 63,700 tons of the fine ship, she would nevertheless require such an enormous excess of power—44,400 I.HP. as against the 18,400 of the fine ship—that the preference would scarcely be accorded to her. For the 15-inch hull the medium ship is indisputably preferable to either of the others, being of only half the size of the full ship, one-third that of the fine ship, and requiring only 13,500 I.HP. against the 18,400 and 44,400 respectively. Even for a 13-inch ship the medium form is unquestionably the best, requiring only the same steam power as the fine ship, and being but $\frac{7}{12}$ of her tonnage.

TABLE II.—SPEED 14 KNOTS.

| Thickness of Hull in Inches. | Fine Ship. | | Medium Ship. | | Full Ship. | |
|---|---|---|---|---|---|---|
| | Displacement. | I. HP. | Displacement. | I. HP. | Displacement. | I. HP. |
| | Tons. | | Tons. | | Tons. | |
| 5 | 3,300 | 2,700 | 3,600 | 4,000 | 8,500 | 14,400 |
| 6 | 3,900 | 3,000 | 4,100 | 4,400 | 9,700 | 15,800 |
| 7 | 4,700 | 3,300 | 4,800 | 4,850 | 11,100 | 17,400 |
| 8 | 5,700 | 3,700 | 5,600 | 5,350 | 13,000 | 19,200 |
| 9 | 7,200 | 4,300 | 6,600 | 6,000 | 15,200 | 21,200 |
| 10 | 9,200 | 5,200 | 7,800 | 6,700 | 18,000 | 23,400 |
| 11 | 12,400 | 6,400 | 9,400 | 7,600 | 21,500 | 26,400 |
| 12 | 17,200 | 8,000 | 11,400 | 8,700 | 26,000 | 30,100 |
| 13 | 24,000 | 10,100 | 14,000 | 10,000 | 31,400 | 34,200 |
| 14 | 37,300 | 13,400 | 17,400 | 11,600 | 37,800 | 38,700 |
| 15 | 63,700 | 18,400 | 22,000 | 13,500 | 46,500 | 44,400 |

In order to illustrate the relations that arise between the medium and the full types at enormous dimensions, the fine type having dropped out of the running, I may say that for 1,000,000 tons of displacement the medium ship would be 23·18 inches thick, and would require 171,500 I.HP. (for the 14 knots), while the full ship would be 22·8 inches thick, and would require double that power.

The principal object which I have in view in unfolding and inviting careful attention to this aspect of the form-of-ship question is to show how necessary it is to be on our guard against a misuse of Constants of Performance. There was a time, and not very long ago, when the opinions formed of the respective merits of ships, even by many professional men, were based almost entirely, or quite entirely, upon comparisons of these constants. Without any regard to their character in other respects, ships were praised or blamed just in proportion to the value ascertained by putting their midship section, displacement, and indicated horse-power into the Admiralty formulas, or some other formula of the kind. The Table that I have given makes the error of this proceeding apparent. The ship with the constant of 160 is, at every point in the Table above 5,000 tons, as we saw, superior in thickness

and strength to the ship of equal displacement with the constant of 230; or if ships of equal strengths be compared, the advantages of the ship with the lower constant becomes immense in the case of the heaviest hulls recorded there. If the form associated with the higher constant 230 (which is that of the fast unarmoured frigate "Shah") were preserved in a ship with a uniform thickness of side and bottom of 15 inches, she would require to be of 63,700 tons displacement to carry the weight and steam the speed required; whereas if the bluffer form associated with the inferior constant is accepted, a ship of 22,000 tons would perform the same service.

Table III. has been worked out with different displacement constants, viz., 250 for the fine ship, 175 for the medium ship, and 130 for the full ship, a given weight (1000 tons), being carried in each case in addition to the steam machinery. The present thickness of the ship's hull varies from 25 inches up to 500. It will be seen from this Table that while the steam-powers requisite for the fine ship, and the medium ship respectively, roughly agree pretty well throughout, the advantage in point of size and first cost are always with the medium ship, and enormously so as the thickness of the hull is increased. Further, the full ship is superior to both the others; for a hull of 50 inches thick, she requires both less size and less power than the medium ship, and although of somewhat greater I.HP. than the fine ship, is of but little more than half the size. For 200 inches and upwards, the short blunt ship, giving a constant of only 130 at 14 knots, is cheaper both in first cost and in working cost than either of the finer ships with higher constants.

TABLE III.

| Thickness of Hull in Inches. | Fine Ship. | | Medium Ship. | | Full Ship. | |
|---|---|---|---|---|---|---|
| | Displacement. | I. HP. | Displacement. | I. HP. | Displacement. | I. HP. |
| | Tons. | | Tons. | | Tons. | |
| 25 | 17,000 | 7,400 | 10,000 | 6,800 | 12,800 | 11,000 |
| 50 | 50,000 | 15,000 | 28,000 | 19,200 | 27,000 | 18,000 |
| 102 | 200,000 | 37,800 | 116,000 | 37,000 | 82,000 | 51,000 |
| 201 | 775,000 | 93,500 | 500,000 | 99,700 | 280,000 | 89,300 |
| 302 | 1,638,000 | 153,000 | 1,000,000 | 157,000 | 573,800 | 145,000 |
| 402 | 2,800,000 | 217,000 | 1,700,000 | 225,000 | 969,500 | 215,000 |
| 510 | .. | .. | 2,750,000 | 305,000 | 1,625,000 | 276,000 |

It must not be thought that owing to the large thicknesses and tonnages here mentioned, the principles involved may be without any practical application of importance to ships of ordinary kind. The ships of small displacement in the Tables are significantly and seriously affected by it, although the advantages and disadvantages are not in the same proportion, or even associated with the same form, in these thinner and smaller ships as in the large ones.

Having now set before you some of those considerations which appear to me of very great importance in determining the forms of all such ships as, from whatever cause, have the weights carried by them varying considerably with their dimensions and proportions, and more especially with their surfaces—whether those weights so carried either form part of them, or are otherwise borne by them—I wish to point out that a due regard to these considerations is very likely to bring upon the best of designs the censure of those who think but superficially upon the subject. I shall be excused if in this connection I derive an illustration from my own practice and experience. The first iron-built iron-clad ship built from my design was the "Bellerophon," already referred to, and she was constructed with a primary regard to those considerations, and although more than successful in every particular, I believe, drew upon herself no little complaint on the ground that her "constants of performance" were much inferior, as they undoubtedly were, and were bound to be, to those of the ships which she was built to supersede, viz., the ships of the "Minotaur" type. There were great differences between the "Bellerophon" and "Minotaur" in armament, armour,[1] &c., but the novel ship was not found fault with on those grounds, as, in point of fact, she carried thicker armour, much heavier guns, was very much handier, and so forth.

For the purposes of the comparison which I am about to make—and which, as you will see, is made solely with the object of illustrating a principle—we may take it for granted that, differing greatly in size as they did, they were about equal in their offensive and defensive powers. But while the "Minotaur" was made 400 feet long in order to obtain fineness of waterlines, the "Bellerophon" was made only 300 feet long, my view being that it was better, when building an armoured hull, and therefore a hull

[1] The "Bellerophon" had the thicker armour of the two, but it was more concentrated. Had this concentration not existed, the average strength of side would have been nearly identical.

of great average weight per square foot of surface, to accept shorter and bluffer waterlines, and give the two ships about equal power. In Table IV. I have brought together the principal particulars of the two ships.

TABLE IV.

| | "Bellerophon." | "Minotaur." |
|---|---|---|
| Length | 300 feet | 400 feet. |
| Breadth | 56 „ 1 inch | 59 „ $4\frac{3}{4}$ inches. |
| Draught of water | 26 „ 7 inches | 26 „ |
| Midship section | 1,330 square feet | 1,300 square feet. |
| Displacement | 7,550 tons | 10,000 tons. |
| Indicated HP. | 6,199 | 6,193 |
| Speed in knots | 14·05 | 14·16 |
| $\frac{S^3 D^{\frac{2}{3}}}{\text{I.H.P.}}$ | 172 | 213 |
| $\frac{S^3 \text{ Mid. Sec.}}{\text{I.H.P.}}$ | 595 | 596 |
| Cost | £342,701 | £456,830 |

On looking superficially at this Table one's first impulse would be to say that we have in the "Bellerophon" a very inferior steamship to the "Minotaur"; for, being a very much smaller ship, she required about the same steam-power to drive her at about the same speed. But now let us consider the matter more closely. The two ships are of equal value, we will presume, for their intended purpose, but the one has cost, as we see, £114,000 more than the other. It would be easy, no doubt, to improve upon the form of the "Bellerophon" in so far as the Displacement Constant of performance is concerned, but as the two ships do the same work, and burn only the same fuel, while the shorter ship is immensely the handier of the two, it would surely be not a very wise proceeding to spend the extra £114,000 by preferring the big ship with the high Displacement Constant to the other. When the "Bellerophon" was tried at the measured mile at Portsmouth, owing to her shortness and fulness, and the certainty of her being a bad performer from the steam-constant point of view, all the authorities at Portsmouth decided in their own minds that she never could steam at more than 11 knots. As a matter of fact, she steamed at $12\frac{1}{4}$ knots with half her power, and exceeded 14 knots with full power. That involved a revolution in the naval design of the country, because, as you are probably aware, there never has been another ship yet built—an iron-clad ship—of the proportions of the "Minotaur" and "Agincourt" class, and probably there never will be.

TABLE V.

| Ships. | Length. | | Breadth. | | Length / Breadth. | Displacement. | I. HP. | Speed Knots. |
|---|---|---|---|---|---|---|---|---|
| | Ft. | In. | Ft. | In. | | Tons. | Tons. | Per hour. |
| New armour-clads . | 340 | 0 | 70 | 0 | 4·86 | 10,470 | 10,000 | 17·0 |
| New belted cruisers | 300 | 0 | 56 | 0 | 5·36 | 5,000 | 8,500 | 18·0 |
| New "Scout" . . | 225 | 0 | 36 | 0 | 6·25 | 1,600 | 3,500 | 16·0 |
| "Oregon" . . . | 520 | 0 | 54 | 0 | 9·63 | 11,270 | 12,380 | 20·0 |
| "Umbria" . . . | 500 | 0 | 57 | 0 | 8·77 | 12,000 | 12,500 | 21·0 |
| "Aurania" . . | 470 | 0 | 57 | 0 | 8·25 | 11,000 | 10,000 | 18·7 |
| "America" . . | 440 | 0 | 51 | 0 | 8·63 | 9,500 | 9,000 | 18·25 |

Before proceeding further, I may be allowed to direct attention, in illustration of the remark that I have just made, to this Table (Table V.). I have here brought together about half-a-dozen ships of quite recent character, to show you in what manner this principle is now recognized. Here are some of the fast Atlantic steam hotels: the "Oregon," the "Umbria," the "Aurania," and the "America," and you see their proportions of length to breadth; the "Oregon," 9·6; the "Umbria," 8·7; the "Aurania," 8·2; the "America," 8·6. The Admiralty have ordered some new iron-clad ships, which also go at the high speed here given. The armour-clads are to go at 17 knots. Look at the proportions: 4·8 is the proportion of length to breadth in the new 17-knot armour-clads. And if you take the belted cruisers, which are to go at 18 knots (fortunately, by the force of a little outside pressure, we have got them up to that), you will see the very moderate proportion of 5·3. My own opinion is that they are right enough in those proportions. But perhaps a more remarkable case is to be found in the little vessel, the new "Scout": it is a torpedo-vessel, and at the same time carries armament, and she is to go at 16 knots. I do not know why the speed is only 16 knots, because the new ships building for all other Governments are going at 18 and 19 knots; but with 16-knots speed in an extremely thin ship, the proportion is only 6·25. I cannot speak with the same approval of that, from the speed point of view, as I do of the others, but I will not doubt that, for considerations of handiness and so on, the Admiralty constructors are right in keeping the proportion down as they have done in that case.

I have already pointed out that if you follow these views and depart from the form of least resistance, which has a fascination for some minds, you are very liable to incur considerable criticism and censure. There are people who cannot get away from formulas which express in their judgment the value of ships; and it is most natural that in cases of steam performance they should be regulated by the indications of a formula. But I do hope I have sufficiently justified my conviction, which is this: that the merit of a naval constructor may often be that he cuts a bad figure in constants of steam performance: that fact may show that he has kept more important objects fully in view.

In making the preceding comparisons between fine, medium and full forms of ships I have employed the Admiralty Displacement Constant of performance, as you know; and it will be obvious to you that whatever may be the measure of the error which that formula involves it can hardly be such as to do more than modify in some degree those comparisons. If we possessed a simple formula based upon a general and correct law of aggregate resistance—at present we have no such formula—we should doubtless be able to deduce from it the same lesson as that which I have drawn from the Table previously given.

The next consideration to which I invite attention is the larger extent to which the breadth and midship section of a vessel, in relation to her other dimensions, may be carried without the sacrifice of the steaming performance. Both the Mercantile and the Royal Navies have of late furnished repeated illustrations of this. The instance which I have selected is that of a contrast between two gunboats of comparatively recent date, viz., the "Medway" and the "Snake," the particulars of which are set forth in the accompanying Table VI., and in Fig. 3, Plate 6:—

TABLE VI.

| | River Gun-boat "Medway." | Gun-boat "Snake." |
|---|---|---|
| Length | 110 feet | 160 feet. |
| Breadth | 34 „ | 25 „ 4 inches. |
| Proportion of length to breadth | 3·24 | 6·32 |
| Mean draught of water | 5 feet 8 inches | 9 feet 7 „ |
| Area of midship section | 172 square feet | 179 square feet. |
| Displacement | 350 tons | 482 tons. |
| Indicated HP. | 314 | 460 |
| Speed in knots | 9·5 | 10·3 |
| $\frac{S^3 \text{ Mid. Sec.}}{\text{I.H.P.}}$ | 472 | 425·8 |
| $\frac{S^3 D^{\frac{2}{3}}}{\text{I.H.P.}}$ | 136 | 146·2 |

In this comparison the "Snake" gets some advantages from the increased size (being about one-third larger) and almost double draught of water. The much smaller and shallower boat has nearly an equal section owing to her excessive breadth, and nevertheless, with a length only $3\frac{1}{4}$ times her breadth, exhibits, at a speed not very much below that of the other, a steam performance on the whole decidedly superior to the other's. I may mention that when about to build the "Medway" class of river gunboat the Admiralty constructors at first thought of making them 110 feet long, but of only 26 feet in breadth. A doubt arising in their minds upon the subject, the late Mr. William Froude—a man whose memory will ever be respected in connection with this subject—performed some experiments upon models which satisfied the Admiralty officers that a substantial gain, rather than a loss, would result from giving them much greater beam, and his anticipation was certainly verified.

Another and more striking instance of the advantage of combining great breadth and section with fine water-lines as a means of obtaining a given displacement under certain circumstances, is shown in another experiment conducted by the late Mr. Froude. This experiment was described by his son, Mr. R. E. Froude, in a Paper appended to the Report of the Inquiry into the condition of H.M.S. "Inflexible." H.M.S. "Ajax" is a vessel of the "Inflexible" type, but smaller, and the object of the experiment was to ascertain what would have been the effect upon the speed of those ships had their beams been greatly increased for the purpose of increasing their stability, their midship sections being also much increased, but their lengths, draught of water, and displacements, all remaining unaltered in each case. A model of the "Ajax" on the scale of about $\frac{1}{36}$ of the full size was made, and for comparison with it a model of an imaginary ship of equal displacement on the same scale. The dimensions of the models were as follows:—

| | "Ajax" Model. | Imaginary Ship Model. |
|---|---|---|
| Length . . . . . . . . | 7·78 feet | 7·78 feet. |
| Breadth . . . . . . . | 1·83 foot | 2·48 „ |
| Draught of water (mean) . | 0·632 „ | 0·632 foot |
| Displacement (in fresh water) | 384 lbs. | 385 lbs. |
| Area of midship section . . | 152 square inches. | 196 square inches. |

I am not able to give the diagrams showing the correct forms of these models, but you will be able to conceive a general idea of them from the figures just given, aided by Fig. 4, Plate 6, in which the continuous line represents a water-line of the "Ajax" model

at half the immersed depth, and the broken line represents approximately a water-line similarly situated on the model of the imaginary ship. These models were towed in the Torquay water-trough or tank with the following results, as transferred to more than the full-size scale, giving the two designs the same displacements, or thereabout:—

TABLE VII.

| Type of Ship. | Length in Feet. | Beam in Feet. | Mean Draught in Feet. | Midship Section in Square Feet. | Displacement in Tons. | Resistance in Tons. | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 12 Knots. | 13 Knots. | 14 Knots. |
| Enlarged "Ajax" | 320 | 75·4 | 26 | 1,788 | 12,240 | 22·2 | 27·8 | 38·1 |
| Imaginary ship | 320 | 102·1 | 26 | 2,306 | 12,260 | 21·8 | 26·4 | 32·1 |

It will be seen from this Table not only that the ship of much greater beam and midship section is subject to less resistance than the other, but that her resistance increases with increase of speed at a lower rate than that of the other vessel.

It is almost incumbent upon me now to notice, however briefly, the position in which we at present stand as regards those doctrines of fluid resistance, &c., to which I have but very lightly adverted in what has gone before. And marvellous indeed are the transformations and extensions which some of those doctrines have undergone during the life-time of many of us now present—marvellous not only in their results, but likewise in the modes and processes of thought by which they have been reached. For it is to be observed, that the nature of the resistances which water opposes to the motions of ships have really been arrived at by aid of very abstract considerations indeed, viz., those dealing with the imaginary movements of those perfect fluids which are themselves imaginary. A perfect fluid would be one of which the particles were free to move among each other, or past an immersed surface, without friction. Such a fluid, if of indefinite extent, would undergo increases and diminutions of pressure in places on a deeply-immersed solid body being moved from rest within it, and would continue to experience differences of pressure all the time the body advanced with accelerated motion. It would respond to these differences of pressure by imparting velocity to certain of its own particles which lay in or near to the path of the advancing body. These particles, moving with varying velocity on lines now called stream lines, would close in behind the disturbing body as it passed onward, coming to rest when excess of

pressure ceased to operate upon them. If now we suppose the body to advance with uniform velocity in this perfect fluid, the positive and negative pressures upon it will, as we know by the laws of fluid motion, be precisely equal; therefore no loss of energy will result; no inducement to the body to stop or slacken its progress will exist; and it will move steadily forward without any reduction of speed whatever. Bring such a body from the deep interior to the surface of a perfect fluid, however, and this state of things will no longer exist. The vertical reactions of the water from above the body will be lost; an upward movement of the parts of the fluid will take place; this upward movement will result in the formation of waves; gravitation will begin to level these waves as soon as they are created; and energy will consequently be lost. Hence, even were water a perfect fluid, energy would have to be expended upon a floating body to keep it moving at a uniform speed, and this energy would of course be the exact equivalent of the energy expended by what would be called the fluid resistance. Here we have, therefore, in the production of waves at the surface, a primary element of resistance, which clearly will not be diminished by the substitution of water for a perfect fluid. With this substitution, on the contrary, there will enter a second element of resistance, viz., that due to the friction and viscosity of the water, which oppose every movement of the particles, whether that movement be among the particles themselves or past the surface of the moving body. And there is a third element of resistance which will enter at the same time, viz., that due to the energy expended upon the production of eddies by abrupt interferences with the general movements of the body and of the water, should such exist. These eddies would obviously not exist in a perfect fluid of indefinite extent in all directions, for there no such loss of energy could take place. I need hardly say that in the foregoing brief account of the now-received doctrine of the elements of resistance, I have merely summarised the views arrived at by the combined labours of Stokes, Rankine, Froude, and others.

In dealing with actual ships, not only have the foregoing elements of resistance to be considered, but account has also to be taken of other interferences with the performances of ships, some of which have the effect of virtually adding to the resistance experienced, while others may be more properly regarded as affecting the efficiency of the forces which propel the ship.

Of the former class I will select for mention that effect of a steam-propeller which retards or prevents the stream-lines of the

fluid from duly closing in upon the run or after body of the ship, and contributing as much as they would otherwise contribute to the advance of the ship. In a perfect fluid of indefinite extent, and in the case of a ship moving with uniform velocity, the energy expended on the bow or fore-body of the ship would be fully restored by the closing in of the fluid (moving in stream lines) upon the stern or after body. But this closing in of the fluid upon the after part is interfered with in the case of a ship propelled by the paddle or screw, not only by the viscosity and friction of the fluid, &c., but also by the fact that the propeller more especially if it be a screw, takes direct effect in driving astern the water which is seeking to follow and to close upon the ship. If the propeller, even where it is a screw-propeller, were placed sufficiently astern of the ship to allow the stream lines—such as they are in the case of a viscous and imperfect fluid like water—to complete their return to parallelism, so to speak, the propeller would be responsible for those losses only which were due to its own imperfections. But placed where it usually is, it is responsible likewise for breaking in upon the stream-line action of the water, thus diverting it more or less from its natural embrace of the ship, and adding much more largely than many might suppose to the balance of resistance imposed upon her. In cases, not a few, the screw propeller has been placed so near to the stern-post, or close to so broad a stern-post in wood ships, or behind so full a run in ships badly formed for their speed, that the usual excess of resistance due to the cause under consideration has been still further aggravated to the great injury of the steam performance. This injurious effect of the screw in augmenting the resistance by reducing the pressure on the stern was subjected to experimental investigation by the late Mr. Froude, who adopted the device of running a screw just astern of a model by independent means, and measuring the augmentation of resistance thus occasioned. His experiments showed that "with ships of ordinary form, the augment is from 40 to 50 per cent. of the ship's net resistance."[1] "I think," said Mr. Froude, "if the screw were placed something like a quarter of the ship's beam astern of the ship, it would be a great advantage, and probably would reduce the loss to 8 or 10 per cent." He also said, "It is a most remarkable thing to find at how great a distance it produces a sensible increase of resistance." . . . . "I found that when the screw was removed to about one-third of the ship's

[1] Trans. Inst. Naval Architects, vol. xvii., pp. 174, 180.

breadth from the stern the maximum effect of advantage was produced, but even then there was some little augmentation of resistance." So far as I am aware, there have been no experiments serving to show to what extent this cause of augmentation of the effective resistance is relieved by increased fineness in the ship's run; but the very nature of it is such as to suggest that every approach to fulness in the after water-lines must be objectionable, and should be avoided throughout the whole immersed depths of the stern—a point well worthy of the naval designer's attention in these days of high speeds.

Another point of considerable importance to the steaming capabilities of a ship, as affecting the effective resistance which she experiences, is the relation of her form to the wave-system which she sets up when driven at a uniform speed in comparatively smooth water. This is a subject of great importance, but one which is as yet so imperfectly developed that it can hardly be regarded as playing any active part in the determination of the forms of ships, although there are some constructors who are doubtless giving it attention. It is well known to most persons connected or acquainted with the mercantile marine, that very diverse results have been experienced by those who have lengthened steamships. In some cases a considerable addition to the length of a ship's middle or parallel body has been made with great advantage to her steaming performances; in other cases, the results have been disappointing. No formula known at the time, and I believe no formula known at present, offers any explanation of these discrepancies. But here again the late Mr. Froude stepped in, and, although he did not furnish, and could not have furnished quantitative solutions of the problem, or devise formulas for such solutions, he certainly opened up a path which we may hope will one day lead to them, especially as his mantle has fallen upon a son, Mr. R. E. Froude, who is following up his father's labours with surprising ability and success. And as it is impossible to do any sort of justice to this subject without frequent references to the experimental labours of the Froudes at Torquay, it may, perhaps, be permitted me to claim a vital, although but a remote interest in those labours, by quoting a sentence from a biographical notice of my deceased friend Froude, the writer of which says:—"Mr. E. J. Reed, then Chief Constructor of the Navy, saw the importance of encouraging a method of thus economically ascertaining the resistance of ships; and having visited Mr. Froude, and seen the experimental results, he requested Mr. Froude to put into a definite proposal his

willingness to conduct a series of experiments for the Admiralty." [1] Having thus initiated, as it were, that long course of Admiralty experiments, by means of which the Froudes have endowed the civil engineer and naval constructor with such priceless scientific results, I trust you will permit me to make such frequent reference thereto as I may find necessary.

The further element of resistance now to be mentioned lies beyond the wave-making element of resistance already explained, and depends upon the waves produced by the bow coming into such relations with the stern and with the stern-wave, as to cause either an additional resistance, or a forward force which partly counterbalances the resistance originally due to their creation. Whether an augmentation or a diminution of resistance is thus brought about depends, with given entrances and runs, upon the distance at which these are kept apart by various lengths of parallel, or nearly parallel, middle body. If the ship is so formed that the wave produced at the bow remains large enough on reaching the stern to produce the effect here spoken of, then if the crest of the wave happens to fall at a certain distance forward of the stern-post, the effect will be to assist in the propulsion of the ship; if the hollow fall at that place, the opposite effect will occur, and the resistance will be augmented. The first idea was that these results were due to increases or decreases of hydrostatical pressure upon the after body of the ship; but the stream-line theory, indeed, the theory of waves itself, is scarcely consistent with this conception of the matter; nor is it any more consistent with either theory to suppose that the bow-created wave can at one and the same time exert its energy upon the stern in forward effect, and leave the stern-wave unaffected. The very existence of the stern-wave implies the absence of the bow-wave energy, and if the latter were fully restored, the reason for the former would be gone. Mr. R. E. Froude has seen this quite clearly. He has said,[2] "The bow-wave in being absorbed must do something to the stern-wave;" and his most reasonable suggestion is, that the action of the bow-wave at the stern is that of arresting the formation of the stern-wave—"That, in fact, the function of the afterbody, when advancing into water already in a certain state of wave-motion, is to "swallow up that wave instead of making any of its own." And he adds, "If so, the placing of the afterbody in the most favour-

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[1] Trans. Inst. Naval Architects, vol. xx., p, 266.
[2] Ibid., vol. xxii., p. 229.

able position in reference to the bow-wave series, has a double benefit: (1) The bow-waves restore their energy, and are absorbed; and (2) in doing so, they prevent the expenditure of energy in making stern-waves."

But whatever may be the correct theory of the matter, the Torquay experiments established in a satisfactory manner that it is highly desirable so to form the ship as to bring the crest of the bow-formed wave into a suitable relation to her stern, a very considerable reduction of net resistance being thus secured. All this presumes, of course, that the *speed* of your ship is defined; for it need hardly be said, that the train of waves set up by a given ship in uniform motion varies with every variation in the speed at which the uniform motion is to take place.

The element of resistance due to eddy-making, which I have mentioned in passing, is of very considerable importance, and its existence has suggested the great desirability of avoiding, as far as possible, everything which can give rise to it. This is especially important in twin-screw ships of high speed, because of the drag of the shaft brackets—sometimes four in number—through the water. All such things should be tapered fore and aft, the fineness of the taper towards the stern being of much importance.

Of the three contributing elements of resistance, that of friction is nearly always the largest in amount. It is regarded as being regulated by the extent of the immersed surface of the ship, the roughness of that surface, and the speed, varying approximately with the square of the speed. Ordinarily it is not dependent upon the form of the immersed body of the ship, although there are doubtless some exceptions to be made to this. For low speeds it usually occasions about $\frac{9}{10}$ of the total resistance, and even at very high speeds exceeds one-half of it. The resistance due to eddy-making is small in ordinary ships, not exceeding one-tenth of the resistance due to friction. The resistance to wave-creating is of much more serious amount, approaching at high speeds to the frictional resistance.

Speaking to professional men I feel that I should be wanting both to you and to myself if, before concluding, I did not express some opinion upon that most important outcome of all ship-questions, viz., their relation to the naval eminence of this country. I have adduced to you several illustrations of the fact that the construction of ships with thick sides—of armoured ships—while imposing upon us great changes of form and proportions, is not by any means necessarily attended by those enormous increases of

dimensions which those might suppose who are familiar only with commercial ships. On the contrary, we have seen, that while long fine-lined ships built of thick armour would require to be of enormous size and power even to float, ships of shorter and fuller forms are vastly more economical, and can be driven at high speeds with much less power. Into the methods and devices by which the extent of armoured surface can be reduced, while remaining ample (while it remains intact) to preserve the buoyancy and stability of the ship, there has not been time to enter. But you will perhaps accept from me the assurance that the resources of science in this respect have not by any means been exhausted, or even seriously drawn upon, as yet. Great impediments to their employment exist, among which I may mention the restrictive influences of our stone docks, and the absence of floating iron docks capable of receiving ships of any required size or form. But all such impediments can be overcome, by the engineer at least, and, so far as we are concerned, there is no difficulty in producing armoured ships of great breadth. We require such ships not only for the purpose of economizing the amount of the armour employed in proportion to the stability and buoyancy protected, but also for the purpose of keeping the ram and the torpedo at an ample distance from the boilers and magazines, which should in fact be protected by an inner citadel, so to speak, well removed from the outer one. All these possibilities of naval development have, however, been abandoned, and for many years past the construction of armoured ships has itself been given up in this country—armoured ships being those which have a sufficient volume protected above water to keep them afloat and from capsizing all the time the armour is unpenetrated. The production of such ships has been left to those foreigners who may care more than we do for power and endurance in battle. But I wish to say that neither true science nor sound engineering has made necessary or sanctioned this surrender. So far is that from being the case, the recent developments of science, as Froude and others have shown, have facilitated, and even invited as sound and beneficial, that very resort to increase of breadth, &c., which the development of the war-ship needed. They have shown us clearly that a combination of practical invulnerability and high speed is perfectly possible. Of course an invulnerable high-speed ship must in these days be a large ship, and size and cost are the bugbears of our politico-naval administration. By the true engineer they are, however, justly regarded as secondary to great and noble objects, among which surely ought to be comprised the naval pre-eminence of our country. At any

rate I maintain that there is no engineering obstacle whatever to England constructing and sending to sea not merely those great and fast but delicate and fragile Atlantic hotels in which the British Navy is now to embark and fight, for the want of anything better, but war-ships, real war-ships, almost as invulnerable as these islands themselves, and capable of bearing the once-proud flag of England boldly into the waters of any enemy whatever.

Sir F. Bramwell, President: Gentlemen, your acclamations have forestalled the proposition I was about to make, namely, that we should give our best thanks to the lecturer of this evening. I am sure you will agree with me that the Institution is fortunate in having among its members a gentleman like Sir Edward Reed, competent to deal in the manner in which he has dealt to-night with so important a subject, and done so with a weight of authority which few can equally possess, and none claim to have in greater measure. Notwithstanding the clear manifestation of approval which you have already given, it is Sir Edward Reed's due that there should be on record a formal vote of thanks. I therefore beg leave to propose that the very best thanks of the members are due to Sir Edward Reed for the able and instructive lecture on "Forms of Ships," which he has given us this evening.

Mr. Abernethy, Past-President: I have pleasure in seconding the vote of thanks proposed by our President for the very able lecture that we have heard to-night upon a most important part of engineering science—one of the most important perhaps of the present day. I think also it is due to the gentlemen who have delivered the previous lectures that we should return our sincere thanks to them for the very valuable additions they have made to our scientific knowledge.

Sir F. Bramwell, President: It is now my duty to ask you, on this the concluding evening, to return your thanks to Mr. Evans, Dr. Pole, Professor Unwin, Sir Charles Hartley, Mr. Stevenson, and the lecturer of this evening, Sir Edward Reed, for having so ably and clearly brought before us the various branches of this session's course of lectures—Hydro-Mechanics—a subject of vast importance to the engineer, and one that has been fortunate in being represented by gentlemen of the rare ability and distinguished position possessed by each of the lecturers, to whom I now ask you to return the sincere and hearty thanks which they so richly merit.

The resolution was unanimously agreed to.

Sir Edward Reed: Mr. President and Gentlemen—It is my duty

to thank you on behalf of those gentlemen who have lectured on former occasions during the session. I am quite sure that all the members of this Institution, and pre-eminently the members of the Council who are entrusted by your suffrages with the responsibility of managing it, are most anxious to serve you in any way they can, and are very proud to have had the opportunity of delivering their respective lectures. For my part I confess I feel some compunction in having detained you so long a time with a lecture which was necessarily more or less imperfect. I thank you sincerely, however, for the patience and careful attention with which you have listened to me. Although I for one feel that it must be a great tax upon members of the Institution to be required to attend here twice a week, it is on the other hand no tax to those gentlemen who have the honour of being invited by the Council to deliver lectures, but it is a very great privilege, while you are willing to come and listen, for them to do their best to interest you, and to suggest matters for your consideration which they hope will not be without some advantage.

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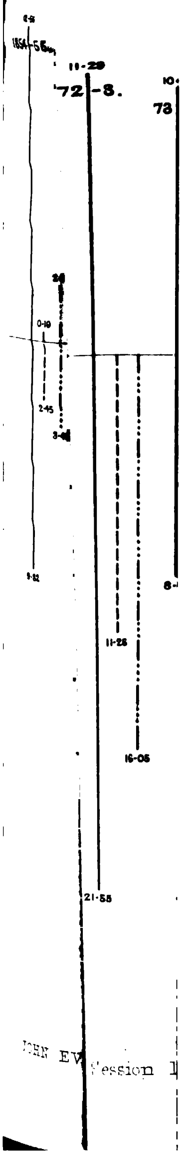


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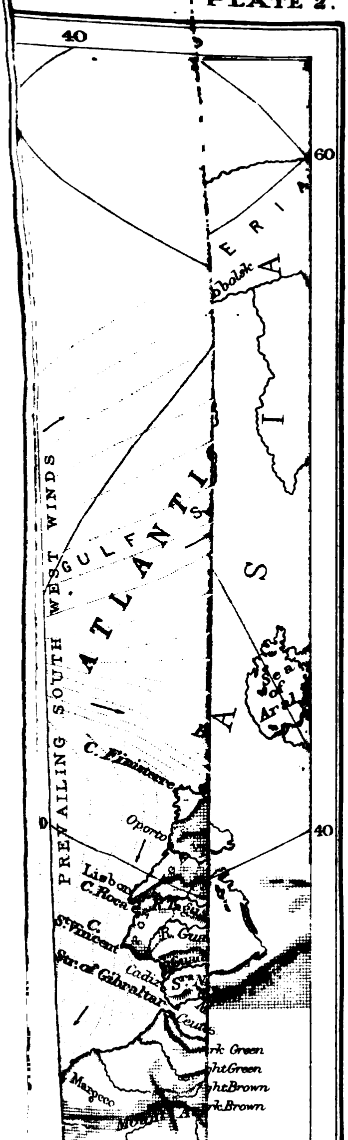


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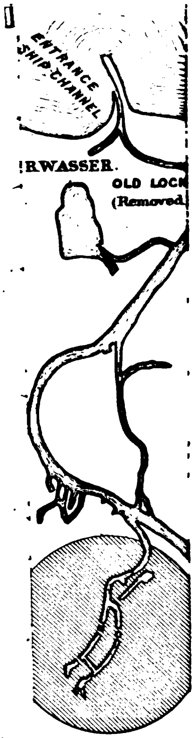
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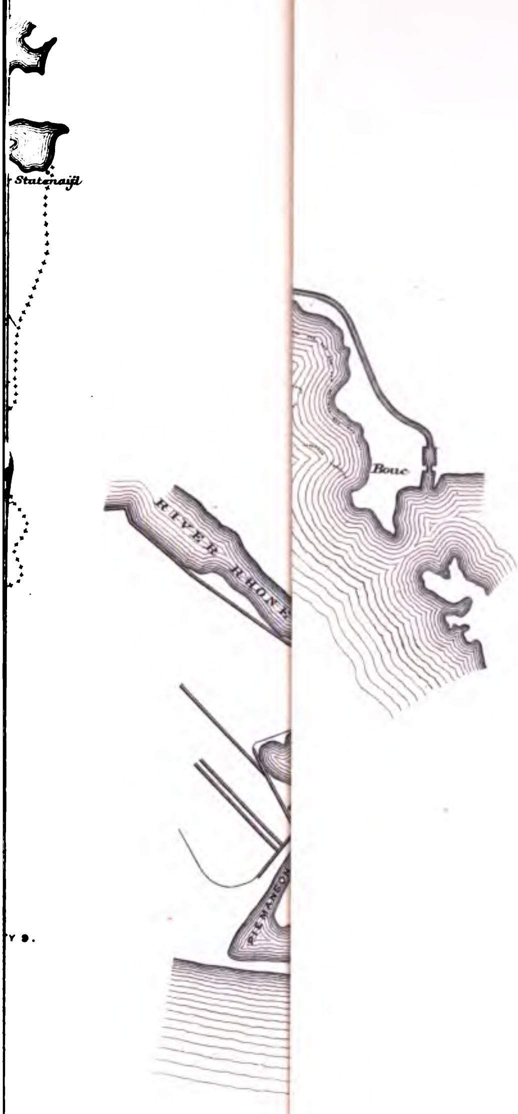


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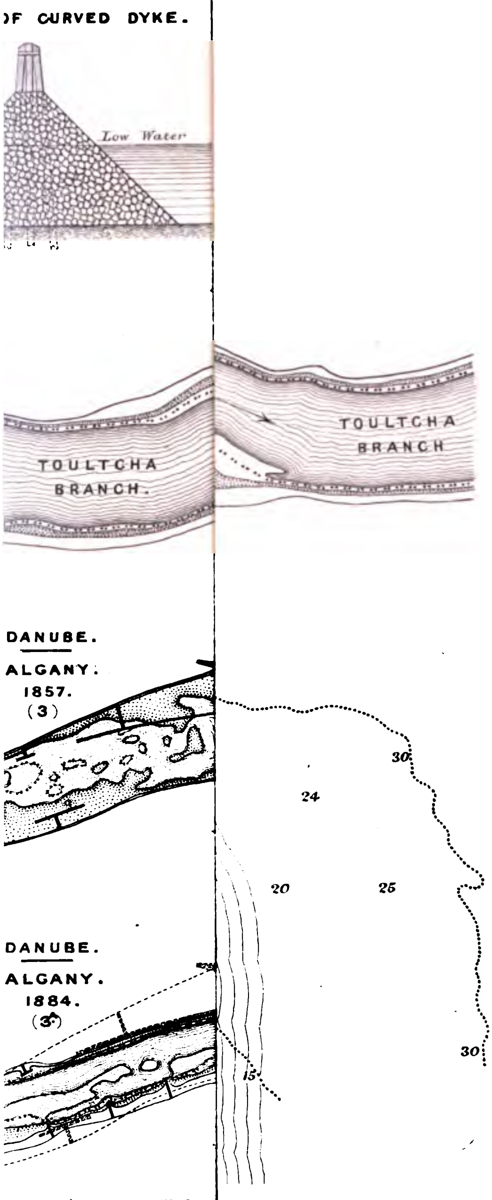


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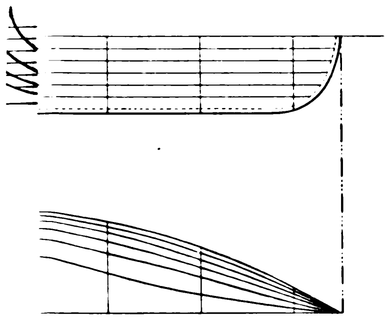

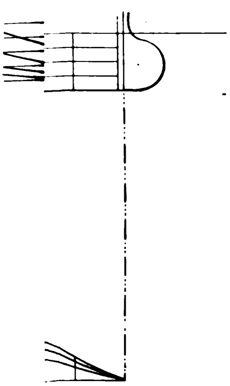

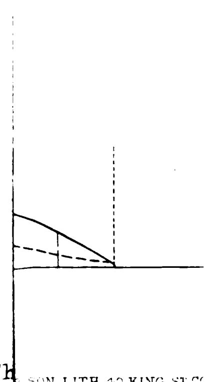

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